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Modeling linguistic intuitionistic fuzzy preference into the consensus and dissent framework of graph model for conflict resolution and its application

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ABSTRACT

The intensification of water scarcity and pollution has elevated the strategic significance of cross-border water resources. Their transnational nature complicates ownership and use rights, leading to conflicts. The graph model for conflict resolution (GMCR) has proven effective in addressing strategic disputes. However, decision-makers' preferences, influenced by a complex interplay of cultural, economic, and political factors, are too intricate to quantify precisely in cross-border water resource conflicts. Besides, despite the importance of consensus being widely researched in the group decision-making field, its study within GMCR remains limited. To address these challenges, we develop a new consensus and dissent framework of GMCR with linguistic intuitionistic fuzzy preference relations (LIFPRs). As a qualitative tool, LIFPRs composed of linguistic intuitionistic fuzzy numbers (LIFNs) can capture DMs' certainty, uncertainty, and hesitation. Specifically, we first propose a score function of LIFNs and some necessary definitions to model LIFPRs into GMCR. Then, we study the consensus and dissent framework of GMCR with LIFPRs in logical form. Additionally, we provide the corresponding matrix representation for future decision support system development. This study is applied to the Mekong River conflict, suggesting that the Mekong River Commission and China should engage in a comprehensive cooperative negotiation process.

1. Introduction

Economic and societal development, coupled with rapid population growth and the consequent increase in water demand, has led to increasingly severe water scarcity and pollution [1]. In this context, cross-border water resources have gradually become a strategic economic resource for countries, and their importance is self-evident. The transnational nature of cross-border water resources implies shared ownership among basin countries. However, governance systems are often complex due to overlapping claims regarding ownership, usage rights, and regulatory responsibilities. Unclear cross-border water rights and a lack of robust regulatory systems can lead some basin countries to adopt independent development models based solely on their own water needs, neglecting the overall ecological environment of the basin. This can harm the interests of other basin countries, resulting in ongoing conflicts [2]. Mild water conflicts can lead to political, economic, environmental, and civil disputes; severe ones can even cause

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Full length article

A novel graph model for resolving power-asymmetric conflicts: Application in hierarchical diagnosis and treatment systems

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Hierarchical diagnosis and treatment system
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ABSTRACT

As Chinese society undergoes rapid aging and urbanization, the existing medical service system faces significant challenges, including unequal resource distribution, a shortage of high-quality resources, and inefficient allocation. To address these issues, the hierarchical diagnosis and treatment system (HDTS) has been introduced to optimize medical resource allocation and utilization. However, implementing HDTS encounters complex conflicts of interest among multiple decision-makers (DMs), compounded by ambiguity, uncertainty, and power asymmetry. This paper proposes the power-asymmetric additive graph model for conflict resolution (PAAGMCR), a versatile tool that integrates qualitative and quantitative methods to address stakeholder conflict in HDTS implementation in Shandong, China. The optimal solution r_H can be identified using PAAGMCR: the Shandong Provincial Government should standardize medical treatment processes in tertiary hospitals, invest in grassroots medical facilities, allocate funds for public awareness campaigns, and encourage patients to seek initial treatment at the grassroots level. Tertiary hospitals should collaborate with grassroots hospitals to utilize subsidies for equipment upgrades and workforce training. Patients and their families should adhere to HDTS principles and make informed healthcare decisions. Furthermore, this study outlines an evolutionary path from the initial to the optimal state, offering theoretical support for resolving real-world conflicts. Finally, strategic recommendations are provided according to the analysis result of the conflict to guide DMs in implementing HDTS effectively.

1. Introduction

The allocation of medical resources in China exhibits a pronounced "inverted pyramid" structure, with tertiary hospitals concentrating the majority of resources, including advanced equipment, highly skilled medical personnel, and extensive clinical expertise [1]. In contrast, primary healthcare institutions face a relative lack of resources. This tertiary-centric diagnostic and treatment model not only over utilizes high-quality medical resources for common and frequent ailments but also increases patients' inconvenience and financial burdens. Simultaneously, primary healthcare institutions struggle with underutilized resources and declining patient patronage [2]. This imbalance, coupled with the growing medical demands of an aging population, hampers the operational efficiency of China's healthcare system and significantly constrains the pursuit of high-quality development in the health sector.

To address these challenges, the Chinese government issued the "*Guiding Opinions of the General Office of the State Council on Advancing the Establishment of a Hierarchical Diagnosis and Treatment System*" in 2015 [3]. This policy emphasizes prioritizing the redistribution of high-quality medical resources, promoting the vertical flow of healthcare services, and improving the efficiency and overall benefits of resource utilization. Its goal is to establish an organized medical service framework that positions primary healthcare institutions as the initial point of contact, facilitates bidirectional referrals, differentiates treatment for acute and chronic conditions, and ensures vertical integration across various levels of healthcare providers [4]. The hierarchical diagnosis and treatment system (HDTS) is recognized as a pivotal mechanism for optimizing resource allocation and ultimately improving the population's health outcomes [5].

Since the inception of the HDTS in China, Shandong Province has implemented tailored strategies to promote its development. The "*Implementation Opinions of the General Office of the Shandong Provincial People's Government on Promoting the Establishment of the HDTS*" [6] outlined a phased roadmap: initiating pilot projects in selected prefecture-level cities in 2015, expanding the pilot regions in 2016, establishing the HDTS and

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A new linguisitic three-way decision model for multi-attribute group decision making problems under inconsistent group opinions

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ABSTRACT

In real-world linguistic multi-attribute group decision-making (LMAGDM) scenarios, conflicting attributes, differing opinions among stakeholders or factors such as decision costs and high risks often arise, making it challenging to find alternatives that simultaneously satisfy all attributes. It often involves multiple rounds of decision-making. However, the traditional LMAGDM methods aim to rank or prioritize limited alternatives, resulting in binary decision outcomes where alternatives are either accepted or rejected. Such binary decision outcomes are overly stringent and did not align well with human cognitive habits. Moreover, inconsistency in group opinions often prevails in LMAGDM scenarios. To address these issues, a relevant linguistic multiple attribute three-way group decision-making (LMA3WGDM) approach is established. First, linguistic loss functions derived from LMAGDM are discussed, and a special linguistic three-way decision model is developed. Then, the LMA3WGDM method is established founded upon fuzzy equivalence clustering method and linguistic partitioned Maclaurin symmetric mean operator (LPMSM) operator to address the inconsistency in group opinions. Lastly, the established LMA3WGDM approach is applied to green supplier selection and subjected to sensitivity analysis and comparative analysis to demonstrate that the established LMA3WGDM approach represents a significant advancement in handling inconsistency in group opinions, and also more conforming to typical decision-making scenarios in real world than the traditional LMAGDM methods.

1. Introduction

As an essential component of the present decision-making science, multi-attribute decision making (MADM) means the decision-making process of selecting or ranking limited alternatives under the consideration of multiple attributes. MADM problems pervade various sectors, including science and technology (Li et al., 2020), economy (Ibdi & Heidari, 2023; Wang et al., 2024), engineering (Li & Hu 2023; Yang et al., 2020), management (Li et al., 2024; Yang et al., 2022), and military affairs (AlMaad et al., 2023), among others. In pace with knowledge-economy development and science-technology progress, real-world MADM issues have grown increasingly complex. It is evident that the ability of an individual alone is insufficient to address these intricate problems, necessitating multiple stakeholders participating in decision-making analysis, which is also called multi-attribute group decision making (MAGDM) problems. Meanwhile, given the uncertainty and ambiguity inherent in decision-making quandaries, coupled with fuzzy preference of human being, natural language serves as the most apt medium for expressing decision makers' sentiments. Utilizing linguistic (fuzzy) assessments proves to be more pragmatic than relying solely on numerical values in MAGDM problems. Therefore, this paper focuses on linguistic MAGDM (LMAGDM) issues.

The current research in LMAGDM is very rich, and many scholars and experts have proposed many different LMAGDM methods from different perspectives, different theories and different scenarios (Liu et al., 2021; Morente-Molinera et al., 2020; Wang et al., 2023; Zhang et al., 2023). For instance, Liu et al. (2021) proposed a group consensus method based on evidence reasoning. Zhang et al. (Zhang et al., 2023) built a group consensus method around risk avoidance and robust optimization. Wang et al. (Wang et al., 2023) established a LMAGDM method from the perspective of decision-makers' psychological behavior. The above LMAGDM methods primarily aim to rank or prioritize limited alternatives, resulting in binary decision outcomes where alternatives are either accepted or rejected. However, such decision outcomes are often too

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碳配额交易机制下竞争企业低碳技术扩散——基于复杂网络的演化博弈分析

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摘　要　碳配额交易机制被认为是应对全球气候变化最有效的碳减排市场激励手段. 为了探究此机制下企业生产、减排和碳交易的最优决策以及低碳技术的扩散度, 构建了低碳技术-传统技术两种减排博弈模型, 分析各参数对最优决策的影响; 同时, 以 WS 小世界网络为载体, 设计演化规则, 利用数值仿真探索各要素对低碳技术扩散的驱动效应. 结果表明: 微观层面, 碳配额和竞争强度升高对减排水平、碳价格和碳交易量提升无益, 但产量与碳配额正相关, 与竞争强度负相关. 宏观层面, 低碳技术的扩散程度取决于企业间竞争强度以及碳配额水平, 碳配额的降低以及企业竞争强度的减弱都能够促进低碳技术的扩散. 与补贴机制相比, 碳配额交易机制可实现经济效益与环境效益的"双赢", 即碳配额交易机制能够促进低碳技术扩散程度并令企业获得更高利润.

关键词　碳配额交易; 低碳技术扩散; 复杂网络; 演化博弈

Low carbon technology diffusion of competitive firms under cap and trade mechanism — Evolutionary game analysis based on complex network

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Abstract　Cap and trade is considered to be the most effective market incentive mechanism for carbon emission reduction to deal with global climate change. In order to study the optimal decision-making of production, emission reduction and carbon trading as well as the diffusion of low-carbon technology under this mechanism, we build two emission reduction game models of low-carbon technology and traditional technology under cap and trade mechanism for competitive firms. The impact of various parameters on the optimal decision-making is analyzed; at the

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A new multi-objective ensemble wind speed forecasting system: Mixed-frequency interval-valued modeling paradigm

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ABSTRACT

Improving wind speed prediction is essential for increasing the use of wind energy and promoting sustainable utilization of resources. Most previous studies relied on single-valued data with a common frequency, resulting in limited wind energy utilization. To fill this research gap and strengthen the precision of wind speed prediction, this study proposes a new multi-objective ensemble forecasting system based on a mixed-frequency interval-valued modeling paradigm for power system decision-making. The system comprises three modules: interval-valued data preprocessing module, mixed-frequency interval-valued forecasting module, and multi-objective ensemble module. Firstly, to reduce the data complexity by preprocessing the mixed-frequency interval-valued wind speed data, an interval-valued data preprocessing module is designed. Then, different types of prediction models, including a mixed data sampling model, two artificial intelligence models, and a traditional statistical model, are used to predict each subsequence in the mixed-frequency interval-valued forecasting module. Finally, a multi-objective ensemble module is designed to ensemble the interval-valued prediction results of each sub-model, and the final interval-valued wind speed forecast results are obtained. The proposed system obtained IMAE values of 0.4634 and 0.3452 m/s from Inner Mongolia and Penghai, China, respectively; this provides a significant tool for wind speed prediction.

List of abbreviations

AOA	Archimedes Optimization Algorithm
ARIMA	Autoregressive Integrated Moving Average
ARMA	Autoregressive Moving Average
CEEMD	Complete Ensemble Empirical Mode Decomposition
EEMD	Ensemble Empirical Mode Decomposition
ELM	Extreme Learning Machine
EMD	Empirical Mode Decomposition
GMDH	Group Method of Data Handling
GWO	Grey Wolf Optimizer
IAVV	Interval Average Relative Variance
IMAE	Interval Mean Absolute Error
IMAPE	Interval Mean Absolute Percentage Error
I-Matrix	Improvement of Matrix
IRMSE	Interval Root Mean Square Error
ISRE	Interval the Sum of Squared Error
IU	Interval Theil's Statistics
MBDG	Mixed Data Sampling
MOAOA	Multi-objective Archimedes Optimization Algorithm
MOGWO	Multi objective Grey Wolf Optimizer
MOPSO	Multi objective Particle Swarm Optimization
MVMD	Multivariate Variational Mode Decomposition
NWP	Numerical Weather Prediction
OELM	Online Robust Extreme Learning Machine
PSO	Particle Swarm Optimization
VMD	Variational Mode Decomposition
WRF	Weather Research and Forecasting

1. Introduction

The background for wind speed forecasting, a literature review, research content, and the main novelties and contributions of this research are discussed in this section.

2.1. Background

In recent years, rapid economic growth has brought great pressure to

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Decision Support

Trust exploration- and leadership incubation- based opinion dynamics model for social network group decision-making: A quantum theory perspective

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ABSTRACT

Social network (SN) holds significant sway over the consciousness and behavior of involved individuals, serving as an evolutionary medium for opinion dynamics models. Consensus is a fundamental concept in group decision-making (GDM). How to effectively explore the opinion evolution during the consensus reaching process through SN is of paramount significance for decision-making science. Therefore, a dual-mechanism containing trust exploration and leadership incubation is developed for modeling opinion dynamics, creating a favorable condition for achieving consensus. First, a novel mechanism for analyzing the completeness of SN is proposed, encompassing a trust propagation process that considers trust discount and stability, as well as a trust aggregation method grounded by quantum theory. Second, a trust screening rule is discussed to retain the valid indirect trust relationships (TRs), and then a leadership incubation mechanism is developed to promote the effective achievement of consensus opinions in group decision-making. Finally, a numerical study is presented to elucidate the superiority and rationality of the proposed methods, and some simulation experiments and comparative analyses demonstrating the effectiveness and advantages of which are covered.

1. Introduction

The evolution of the internet has dismantled the barriers impeding the flow of information and promoted interpersonal engagement. The interwoven social connections give rise to a social network (SN), gradually evolving into a platform sustaining interpersonal relationships and information sharing. SN has an essential influence on the consensus and behaviors of involved individuals, fostering the emergence of SN group decision-making (SNGDM) (Ding et al., 2023; Liang et al., 2023; Wu, Wang et al., 2022; Xing et al., 2023; Zhang et al., 2022) as a novel paradigm in decision-making. Unlike traditional GDM, SNGDM does not view participants as independent entities, but focuses on their social relationships (SRs). Some of the developed SNGDM methods have primarily utilized SRs, especially trust relationships (TRs), in the following aspects: (1) weights determination of decision-makers (DMs) (Gong et al., 2023; Ji et al., 2023); (2) subgroups discovery in large-scale GDM (LSGDM) (Du et al., 2021; Yu et al., 2021; Yu et al., 2022); (3) estimation of incomplete opinions (Liao et al., 2021; Tian et al., 2023); (4) generation of recommended opinions (Liu et al., 2023b; Zhang et al., 2020); and (5) modeling for opinion dynamics (Ding et al., 2022; Dong et al., 2017; Wu et al., 2023). Actually, the integration of opinion dynamics and SN is complementary. SN can serve as the evolutionary medium for opinion dynamics models, such as the SN-DeGroot (SNDG) model (Xiong et al., 2017). Opinion dynamics models can visualize the impact of TRs on the opinions of DMs, such as the SN-Hegselmann-Krause (SNHK) model (Liang et al., 2020).

Consensus is a fundamental facet in opinion dynamics. Some studies have explored numerous methods for achieving consensus (Chao et al., 2021; Ding et al., 2022; Dong et al., 2017; Liu et al., 2023a). For example, Ding et al. (2023) studied the factors influencing the consensus convergence speed based on the SNDG model. Dong et al. (2017) emphasized the role of opinion leaders in reaching consensus. Liu et al.

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Z-mixture three-sided stable matching in seaborne coal exchange with cooperative partners and heterogeneous relationships among attributes

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ABSTRACT

Three-sided matching decision making (TSMDM) problems are widespread in the real world. In practical TSMDM scenarios, two of the three sides collaborate, and matching objects on each side give their assessments about matching objects on another side according to multi-attributes with heterogeneous relationships. Given the advantages in describing uncertain information and its credibility, Z-mixture number is utilized to represent assessment from matching object, which offers continuous variable or discrete variable leaves matching objects free to choose. Based on this, this paper constructs a multiple attribute TSMDM model with Z-mixture numbers to deal with such situations. First, the prioritized interactive aggregation operator is proposed to aggregate Z-mixture numbers, which takes the prioritization and various interrelationships among the input arguments into account. Second, a weight determination model based on maximal deviation and fuzzy measure is proposed to determine the importance of attribute coalitions. Furthermore, a three-sided stable matching model with cooperation which pursues the maximization of overall satisfaction of matching objects by considering the stable matching conditions is constructed to obtain the stable matching among matching objects. Lastly, a case for the matching of supply, transportation and demand in seaborne coal exchange is presented to validate the rationality and practicability of the proposed method. Compared with the existing studies, the advantages and effectiveness of the proposed method are demonstrated.

1. Introduction

Coal is the main fossil resources and energy, and is the foundation for national economic and social development (Wu, & Chen, 2018; Zeng, Liu, Kuang, Burdett, Masoud, & Chang, 2023). From the geographical distributing of coal resources, the basic trend was that the west of the province was more than the east and the south was more than the north (Ai, Xu, & Guo, 2021). However, the coal consumption base is mainly concentrated in the East and Southwest regions. So, there exists some discordance between coal production and consumption. It promotes the emergence of coal circulation companies, especially coal shipping companies. Given the fluctuation in transportation volume and freight index, there still exist some not harmonious aspects among coal suppliers, demanders, and shipping companies. To change the status quo and achieve a win-win for all three parties-coal enterprise, coal demanders, and coal shipping companies- tripartite efforts are indispensable. Each party has its distinct interests and demands. Once the interests and requests of either party are not met, the three parties cannot establish an effective partnership. The key to successful cooperation lies in matching the interests and demands of all three parties. The above scenario is referred to as "the seaborne coal exchange", which has these characteristics of three-sided stable matching: (1) Three sides of objects, i.e., coal enterprises, coal demanders, and shipping companies; (2) The assessments over matching objects, i.e., coal enterprises evaluate coal demanders or shipping companies separately according to certain guidelines, both coal demanders and shipping companies have to evaluate other two sides separately with respect to their requirements; (3) The matching rules, i.e., each party aims to maximize their own utility. So, it can be regarded as a three-sided stable matching problem (Table 1).

In the whole matching process, there are several situations that need to be noted. One situation is that multiple assessment criterion (i.e., their requirements or guidelines) used to measure the performances of matching objects are not actually independent. There may be prioritization phenomenon among attributes. For example, Coal quality may have higher priority than Response to market demand in measuring the performance of coal enterprises. The satisfaction degree of Coal quality cannot be compensated for by Response to market demand. In addition,

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Evaluation of ecological governance in the Yellow River basin based on Uninorm combination weight and MULTIMOORA-Borda method

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ABSTRACT

As a river of great strategic significance in China, the ecological governance of the Yellow River is an important issue. As a multi-attribute decision-making (MADM) problem, evaluating the ecological governance of the Yellow River involves many evaluation indexes. To accurately measure the importance of each indicator, this paper applies the best-worst method (BWM) based on linguistic variables to calculate the subjective weights of the indexes. The improved grey relational (IGR) method is proposed to calculate the objective weights. And the two weights are combined using the Uninorm operator to obtain the combination weights of the indexes. To evaluate the problem from multiple perspectives, we apply the MULTIMOORA method to the ecological governance problem. Then we propose the novel Borda method to aggregate the three evaluation results obtained by the MULTIMOORA method and thus construct the MULTIMOORA-Borda method. Based on the above methods, we analyze the evaluation results and provide policy recommendations for ecological governance of the Yellow River Basin.

1. Introduction

The Yellow River originates from the Qinghai-Tibet Plateau, an essential ecological barrier across the three significant geographical steps in north China. It connects the northwest plateau with the eastern Bohai Sea and is an essential economic zone and energy base (Wang, 2020; Xu et al., 2022). Due to the complex water flow conditions and frequent water flow disasters, there are still many problems in the Yellow River management, and ecological governance is one of the biggest problems (Chen et al., 2020; Yang et al., 2020; Liu, 2022). The great significance of the Yellow River and its difficulty in ecological governance have led to the ecological governance of the Yellow River Basin receiving much attention.

Due to the complexity of the ecological governance evaluation problem in the Yellow River Basin, multiple attributes affecting ecological governance need to be considered. Therefore, the ecological governance problem can be regarded as a multi-attribute decision-making (MADM) problem. In this paper, we construct an evaluation index system to consider the attributes of ecological governance problems. The evaluation index system is an organic whole with an internal structure composed of multiple indexes that characterize various aspects of the evaluation object and its interconnection (Bohlouli et al., 2017; Zhuang et al., 2022; Jia et al., 2020). Many factors, including economic, social, and environmental aspects, determine the ecological governance of the Yellow River Basin. Therefore, using a comprehensive and systematic evaluation index system to evaluate the ecological governance of the Yellow River Basin can make the evaluation results more scientific and reasonable.

Assigning reasonable weight to each attribute is a premise for scientific ecological governance evaluation. Index weight can be divided into three types:

(1) Subjective weight. Subjective weight is based on the decision-maker (DM)' s experience and personal perception of the importance of each evaluation index. Each evaluation index is compared, assigned, and calculated according to the degree of importance (Wen et al., 2021). Commonly used methods for determining subjective weights include the stepwise weight

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Research Article

An Optimized Association Rules Mining Framework for Chinese Social Insurance Fund Data Auditing

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Association rules mining with the Chinese social insurance fund dataset can effectively discover different kinds of errors, irregularities, and illegal acts by providing auditors with relationships among the items and therefore improve auditing quality and efficiency. However, traditional positive and negative association rules (PNARs) mining algorithms inevitably produce too many meaningless or contradictory rules when these two types of rules are mined simultaneously, which brings a huge challenge to auditors retrieving decision information. Aimed to reduce the quantity of low-reliability PNARs without missing interesting rules, this paper first proposes an improved PNARs mining algorithm with minimum correlation and triple confidence threshold to control the mined rules number by narrowing the range of confidence strings. Then, a novel pruning algorithm based on the inclusion relation of the rule's antecedent and consequent is given to remove those redundant rules. After that, the proposed optimized PNARs mining approach is applied to the Chinese social insurance fund dataset starting with each features influence factors mining using the Fish table. The experimental results with different datasets show that the proposed approach not only can ensure effective and interesting rules extraction but also has better performance than traditional approaches in both accuracy and efficiency, reducing the number of redundant PNARs by over 70.0% with experimental datasets and average 76.9% with auditing data mining, respectively.

1. Introduction

As has been shown that auditing plays a paramount role in the process of realizing effective national governance, ensuring healthy and scientific social and economic development around the world [1, 2]. In the era of big data, most governments and companies have accumulated a large amount of management and transaction data with the development of information technology. Similarly, heterogeneous and various types of big data are creating serious troubles in the auditing field since it is extremely difficult and cumbersome to manually find accounting irregularities and financial fraud information from the data itself at the surface level [3, 4]. As an example, in 2022, nearly twenty-three million deductions, payments, treatments, and other records were submitted to the Social Insurance Fund Information Centre of a province in China every month, containing abundant information along with errors, irregularities, and illegal acts [5]. For auditors, it is a challenging task to identify those abnormal economic behaviors from the huge amount of data currently. Furthermore, traditional audit methods only analyze data accuracy and integrity without discovering the hidden relationship between variables, resulting in low quality and efficiency in auditing [6, 7]. With the change of objectives, tasks, emphases, and modes of national governance, the strategies and methods for auditing should also change accordingly, therefore facilitating fraud clues finding [8, 9]. Many studies [6, 8, 9] have proposed several association rule mining methods aimed at exploring the relationships among fields in audit databases, helping the auditors' decision making with accurate information, including not only positive association rules (PARs) but also negative association rules (NARs), simultaneously. In particular, those NARs provide richer

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A multi-objective *q*-rung orthopair fuzzy programming approach to heterogeneous group decision making

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ABSTRACT

In allusion to heterogeneous multi-criteria group decision making (MCGDM) problems with incomplete weights and *q*-rung orthopair fuzzy (*q*-ROF) truth degrees, where many kinds of criteria values, i.e., crisp values, intervals, trapezoidal fuzzy values, hesitant fuzzy values and *q*-ROF values (*q*-ROFVs), and multiple types of interactions exist, i.e., positive synergetic interactions, negative synergetic interactions and independence, a novel multi-objective *q*-ROF programming approach is proposed. In particular, in order to globally capture the interactions among criteria, Choquet-based relative closeness degrees are developed based on the technique for order performance by similarity to ideal solution (TOPSIS) and the Choquet integral. Then, the *q*-ROF Choquet-based group consistency index (*q*-ROFCGCI) and the *q*-ROF Choquet-based group inconsistency index (*q*-ROFCGII) are defined. Next, to derive optimal 2-additive fuzzy measures on the criteria set and optimal experts' weights, a new multi-objective *q*-ROF mathematical programming model is established by minimizing the *q*-ROFCGII and maximizing the *q*-ROFCGCI. Subsequently, an algorithm based on the adaptive non-dominated sorting genetic algorithm III (A-NSGA-III) is designed to solve the established model. Afterwards, the Choquet-based overall relative closeness degrees of the alternatives are used to obtain their preferred ordering. Finally, the effectiveness and advantage of the proposed approach is verified using four real cases concerning the evaluation of social commerce.

1. Introduction

Social commerce (s-commerce) refers to the use of social media and Web 2.0 tools to enhance the interactions of individuals on the Internet in order to support consumers' acquisition of products and services [9]. In recent years, with the increasing maturity of s-commerce, increasingly more consumers, especially the new generation, have taken part in s-commerce [14]. However, due to the virtual and anonymous nature of s-commerce, consumers cannot see merchants and commodities [35]. There is also a time asymmetry between payment and shipment, which makes it possible for merchants to commit fraud during transactions [3]. For these reasons, consumers may suffer from high credit risks, which would negatively affect their purchase intention. With the help

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Innovative ensemble system based on mixed frequency modeling for wind speed point and interval forecasting

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ABSTRACT

Wind speed forecasting can improve wind energy utilization and is thus highly significant for wind power systems; however, it is a challenging process. Forecasting techniques from previous research were mainly developed using single-frequency-based time series modeling, which has recently become a popular approach. Although mixed-frequency-based modeling has significant potential, research applying this approach to wind speed forecasting is almost nonexistent. To fill this research gap, we developed an innovative ensemble system based on mixed frequency modeling to perform wind speed point and interval forecasting, comprising data preprocessing, mixed frequency modeling, and ensemble forecasting modules. Unlike the methods used in most previous studies, this system exploits the tremendous potential of mixed frequency data. In addition, a multi-objective optimizer-based ensemble forecaster was devised to provide deterministic and uncertain information regarding future wind speed. Furthermore, data preprocessing based on different strategies was applied to improve the performance of multiple forecasting models. An empirical study based on two wind farms shows that the system outperforms benchmark techniques and can be employed for data monitoring and analysis in wind farms or other fields.

1. Introduction

With the rapid development of the global economy, the utilization of fossil energy continues to increase, causing serious problems such as global warming. To bolster economic development and protect the environment, the use of renewable energy has become increasingly common. In recent years, renewable energy has occupied an increasing proportion of the global energy supply. Wind energy, which is among the cleanest renewable energy sources, is considered to be an effective alternative to fossil fuel energy. However, the randomness and nonlinearity of wind speed directly affect the utilization of wind energy [1]. An effective wind speed forecasting model can capture future wind speed changes, which is necessary to ensure adequate and efficient wind power system operation.

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A Multiattribute Group Decision-Making Method With Probabilistic Linguistic Information Based on an Adaptive Consensus Reaching Model and Evidential Reasoning

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***Abstract*—This article proposes a new multiattribute group decision-making (MAGDM) method with probabilistic linguistic information that considers the following three aspects: an allocation of ignorance information, a realization of group consensus, and an aggregation of assessments. To allocate ignorance information, an optimization model based on minimizing the distances among experts is developed. To measure the consensus degree, a consensus index that considers the information granules of linguistic terms (LTs) is defined. On this basis, a suitable optimization model is established to realize the group consensus adaptively by optimizing the allocation of information granules of LTs with the particle swarm optimization (PSO) algorithm. With an objective to reduce the information loss during aggregation phases, the process of generating comprehensive assessments of alternatives with the evidential reasoning (ER) algorithm is presented. Therefore, a new method is developed based on the adaptive consensus reaching (ACR) model and the ER algorithm. Finally, the applicability of the proposed method is demonstrated by solving a selection problem of a financial technology company. Comparative analyses are conducted to show the advantages of the proposed method.**

***Index Terms*—Evidential reasoning (ER) algorithm, information granulation (IG), multiattribute group decision making (MAGDM), probabilistic linguistic term sets (PLTSs).**

I. Introduction

MULTIATTRIBUTE group decision making (MAGDM) is a significant part of the area of decision making.

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The aim of MAGDM is to find the best alternative or obtain the ranking order of alternatives according to the assessments provided by a group of experts regarding multiple attributes. Compared with multiattribute decision making (MADM) with a single expert, MAGDM is conducive to gathering the wisdom of experts in different fields and understanding problems from different perspectives, to improve rationality in decision making. Thus, many studies have been conducted to address MAGDM problems [5], [7], [8], [11]–[17], [37], [50]. Since the process in MAGDM is centered on humans, who arrive with their inherent subjectivity, imprecision, and vagueness in the articulation of opinions, it is advantageous to express evaluations with linguistic information [2].

To effectively express the qualitative linguistic evaluations of experts, several linguistic representation models have been proposed in the existing literature: 1) single linguistic terms [48]; 2) hesitant fuzzy linguistic terms (HFLTs) [30] and unbalanced linguistic assessments (ULAs) [3]; and 3) linguistic distribution assessments (LDAs) [55] and probabilistic linguistic term sets (PLTSs) [25]. Compared with the first two linguistic representation models, the third model can not only express the hesitation information with several linguistic terms (LTs) but also reflect the importance of each LT with a probability. Moreover, PLTSs have an advantage over LDAs when addressing complex situations where partial ignorance exists because they allow the sum probabilities of all LTs to be less than 1. Thus, PLTSs exhibit great flexibility and comprehensiveness in expressing hesitant and ignorant qualitative linguistic evaluations.

With the emergence of PLTSs, they have been widely applied to practical MAGDM problems, such as venture capital [4], personalized restaurant recommendations [28], [51], selection of financial technologies [22], and emergency rescue planning [56]. Moreover, a number of relevant probabilistic linguistic group decision making (PLGDM) methods have been developed. These methods have focused on the following studies.

1) *Allocation of Ignorance Information:* The existence of ignorance information is not rare in practical PLGDM problems due to experts' insufficient knowledge or the complexity of the decision environment. According to the review of [23], the allocation of ignorance information of PLTSs can be divided into five categories according to the

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A mathematical programming method based on prospect theory for online physician selection under an R-set environment

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ABSTRACT

This study develops an R-mathematical programming method for multiple attribute group decision-making (MAGDM) problems with assessment values of alternatives and truth degrees of pairwise alternative comparisons represented by R-sets while the decision maker holds subjective bounded rationality. First, a novel scalar multiplication operation and defuzzification of R-sets are proposed to allow the use of R-sets in MAGDM problems. Subsequently, based on prospect theory and R-sets, a new technique is proposed to compute the individual overall prospect value of an alternative by simultaneously considering the positive ideal solution (PIS) and negative ideal solution (NIS). Additionally, the R-group consistency index (R-GCI) and R-group inconsistency index (R-GII) are defined using the individual overall prospect values of alternatives. The decision makers' weights, attribute weights, PIS, and NIS are estimated by establishing a novel R-mathematical programming model, which is solved by the external archive-based constrained state transition, while the collective overall prospect values are computed to derive the final ranking order of alternatives. Thus, a new R-LINMAP method is developed to solve MAGDM. A practical instance concerning online physician selection is provided with the corresponding sensitive and comparative analyses to verify the applicability, validity, and superiority of the developed method.

1. Introduction

Comparing, choosing, ranking, or sorting alternatives are common decision-making activities that often occur in everyday life. Real-life decision problems, such as green logistics risk assessment [1], stock investment selection [2], and service quality evaluation [3], generally involve multiple assessment attributes and require numerous decision makers (DMs), which makes multi-attribute group decision-making (MAGDM) relevant and worth investigating. Often, in MAGDM problems, the available data are not precise, but rather ambiguous or vague. The concept of a fuzzy set (FS) was proposed by Zadeh [4] to model these data. An important issue when employing FS is to consider reliability or unreliability of them for the problem. Therefore, many different FSs have been introduced, such as hesitant FS (HFS) [5], intuitionistic FS (IFS) [6], q-rung orthopair FS (q-ROFS) [7], Z-number [8], hesitant fuzzy linguistic term set (HFLTS) [9], probabilistic linguistic term sets (PLTS) [10], and flexible linguistic expression (FLE) [11]. Nevertheless, in certain situations, the available imprecise data may also be related to future events or be derived from unreliable sources and consequently exhibit some degree of uncertainty and/or risk. To address this issue, that is, to describe the risk of FSs due to risk factors, the R-number concept [12] was introduced. In R-numbers, risk modelling of the FSs considers the variability of the domain variable, but not the variability of its membership function (MF). In addition, only one source of risk factors associated with FSs is considered. Thus, Seiti et al. [13] presented the concept of R-sets, which generalises FSs, to describe the errors and risks associated with MFs by modelling the risks related to future events and information sources. Table 1 lists the comparison of different fuzzy models with R-sets. Investigating Table 1, it is clear that the R-sets are more capable of addressing the various uncertainties involved in the physician selection problem although all its parameters might not be used in a real-world problem.

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Temporal-spatial evolution of green total factor productivity in China's coastal cities under carbon emission constraints

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ABSTRACT

Coastal cities are the strategic core areas of China's economic growth. Measuring and understanding green total factor productivity (GTFP) growth in coastal cities is an essential prerequisite for achieving high-quality development (HQD). This paper aims to measure the accurate GTFP growth of China's coastal cities and grasp its temporal-spatial evolution. First, a three-stage dynamic analysis model is constructed to calculate the accurate GTFP growth with the effects of external environmental factors and random errors eliminated. In the context of the "3060" double carbon target, carbon reduction poses a challenge to the HQD of the coastal cities. To measure GTFP growth under the carbon emission constraints, carbon emissions are considered as one of the undesired outputs. On this basis, the temporal-spatial evolution of the GTFP index and its spatial effects are further explored using kernel density estimation and spatial Markov chains. The empirical results show that: (i) The adjusted GTFP index after eliminating the effects of environmental factors and random errors is significantly different from the original results. The GTFP index of coastal cities is underestimated without eliminating the effects of environmental factors and random errors. (ii) There are significant differences in the regional distribution of GTFP growth in coastal cities, with cities with faster GTFP growth gathering production factors from adjacent cities and causing a siphon effect. Finally, policy recommendations related to these findings are given.

1. Introduction

China has a continuous coastline of about 18,000 km, which provides a solid foundation for China's remarkable achievements since the Chinese government carried out the reform and opening up policy. The coastal regions are strategic locations for China, supporting 40% of the population and contributing 60% of China's economic activity within less than 10% of the country's land area. However, the outstanding achievements of the coastal regions have arrived at the cost of massive consumption of fossil fuels such as coal, oil, and natural gas, which has caused many environmental pollution problems (Lin and Wang, 2021). The burning of fossil fuels inevitably produces air pollutants such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and volatile organic compounds (VOCs), as well as carbon dioxide (CO_2), one of the leading greenhouse gases (Mo et al., 2020). The 2021 Greenhouse Gas Bulletin issued by the World Meteorological Organization points out that from 1990 to 2020, the warming effect of long-lived greenhouse gases on the climate has increased by 47%, carbon dioxide accounts for about 80% of this increment (Friedlingstein et al., 2011). In September 2020, the Chinese government announced the "3060" double carbon target aiming to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060. In this context, a development pattern based on resource consumption is no longer appropriate for China's coastal regions, and it is necessary to find a new development pattern that balances economic development and carbon emissions in coastal areas.

The report of the 19th National Congress of the Communist Party of China put forward the concept of the high-quality development (HQD), pointing out that China's economy is at a critical stage of shifting from a high-speed growth stage to a HQD stage. The HQD is an intensive development pattern, which emphasizes driving economic development by improving the efficiency of resource use, rather than relying only on a large number of inputs of production factors (Yang et al., 2021b). In the context of the "3060" double carbon target, the HQD of coastal regions has been closely linked to the carbon emissions in the following two aspects. First, the "3060" double carbon target is an inherent requirement for the HQD. Adjusting the energy structure is a critical approach to the "3060" double carbon target. Increasing the proportion of

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A dynamic large-scale multiple attribute group decision-making method with probabilistic linguistic term sets based on trust relationship and opinion correlation

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Evidential reasoning theory

ABSTRACT

Dynamic large-scale multiple attribute group decision making (DLMAGDM) is ubiquitous in many areas of the real world. It is composed of large numbers of decision makers, several continuous periods, alternative set and attribute set changed with time. Given the characteristics implicited in decision-making elements and the advantages of probabilistic linguistic term sets (PLTSs) in modelling uncertainty and complexity of decision makers' subjective opinions, this paper constructs a probabilistic linguistic DLMAGDM method. First of all, a dynamic weight determination model based on trust relationships and evidential conflicts between decision makers is proposed to obtain current dynamic weights of decision makers. Then, a comprehensive hierarchical clustering method that divides large numbers of decision makers into several subgroups is constructed based on three clustering constraints. Moreover, some probabilistic linguistic extended evidential power aggregation operators are proposed to aggregate PLTSs. These operators can appropriately handle the extreme PLTSs and fully consider the role of incomplete probabilistic distributions in PLTSs. In addition, a dynamic decision-making method based on PROMETHEE is developed to determine the final priority order of alternatives according to preferences between alternatives over several periods. Lastly, a case study for supply chain finance risk assessment for several firms in Chinese household appliance industry is utilized to illustrate the practicality and effectiveness of the probabilistic linguistic DLMAGDM method. Furthermore, the comparative analysis with some other existing methods and the sensitivity analysis are made to verify its advantages.

1. Introduction

Multiple attribute decision making, as a pervasive human phenomenon, has penetrated in all the fields of real life and has formed a decision-making framework for assisting decision maker in making proper decision and maximizing the economic and social efficiency [3,29,33]. With interest subjects diversity present situation, public participation consciousness begun to awaken and ascend, and lots of decision makers participate in the decision-making process, hence arousing the desire to explore multiple attribute large-scale group decision making (MALGDM) [27,30,36,46]. Further, with the continual variation of social environment and an endless stream of uncontrolled factors, the practical decision-making problems are full of com-

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A new integrated multi-attribute decision-making approach for mobile medical app evaluation under *q*-rung orthopair fuzzy environment

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ABSTRACT

Mobile medical app evaluation can be modelled as a multi-attribute decision-making (MADM) problem with multiple assessment attributes. Due to the increasing complexity and high uncertainty of decision environments, numerical numbers and/or traditional fuzzy sets may not be appropriate to model attribute information of mobile medical apps. In addition, heterogeneous relationships are often observed among different attributes in various practical decision situations. To deal with these issues, a q-rung orthopair fuzzy (q-ROF) MADM approach, which is a very powerful tool for describing vague information occurring in real decision circumstances, is proposed to handle decision-making problems in medical app evaluation. In particular, q-rung orthopair fuzzy numbers (q-ROFNs) are first applied to better express the preference information and expert assessment information. Then, *q*-ROFNs are extended by combining with Zhenyuan integral, resulting in the q-ROF Zhenyuan integral (q-ROFZI). This integral can capture complementary, redundant and/or independent characteristics among the attributes and is superior to existing operators on *q*-ROFNs. Next, based on the best-worst method (BWM) and Shapley value, two optimization models are constructed to objectively identify optimal fuzzy measures on the attribute set. Finally, a novel integrated *q*-ROF MADM approach is proposed and its computation procedure is presented and illustrated with its application to the problem of mobile medical app evaluation. A comparative analysis is carried out to demonstrate the validity, rationality, robustness and superiority of the developed method.

1. Introduction

While providing convenience for personal health, a mobile medical app is also accompanied by corresponding management problems, such as insufficient user privacy protection, difficult verification of information authenticity, high risk of telemedicine diagnosis and false medical advertisements, etc., which lead to poorer user experience and seriously impair the reputation of doctors and hospitals. In order to enhance the competitiveness and better serve users, mobile medical app evaluation is necessary. Mobile medical app evaluation can be modelled as a multi-attribute decision-making (MADM) problem with multiple assessment attributes, including functionality, safety, interface and reliability. In recent years, several researched have applied MADM-based methodologies to mobile medical app evaluation and selection issues. For example, Li (2018) used the Delphi method and AHP (Analytic Hierarchy Process) model to evaluate mobile medical app. Li et al. (2021) integrated the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and AHP model for the medical and health app user experience evaluation. Considering the complexity of objective things and disturbances from internal or external uncertainty and ambiguity, it is more realistic for expert to describe assessment information using fuzzy numbers (FNs) (Dixit et al., 2020; Venugopal et al., 2022; Sirbiladze, 2021). Based on this observation, Xu (2018) proposed an integrated approach for evaluating mobile medical app based on the AHP model and fuzzy comprehensive evaluation method.

In the existing fuzzy mobile medical app evaluation research, the traditional FNs serve as a tool to represent uncertain information. However, in the real word, for mobile medical app evaluation problems, most of the assessment detailed information is unknown and there exists a high degree of uncertainty. Consequently, it is insufficient to describe

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A novel ensemble model based on artificial intelligence and mixed-frequency techniques for wind speed forecasting

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ABSTRACT

Wind speed forecasting is of prime importance for wind power generation, which can bring tremendous economic, social and environmental benefits. However, previous wind speed forecasting studies mainly focused on proposing hybrid or ensemble models by combining different methods while ignoring the significant opportunities brought by the era of big data. In particular, the research and applications of mixed-frequency data modeling for wind speed forecasting are almost nonexistent, so some valuable issues remain and need to be studied in depth. In this context, a novel ensemble model, which successfully introduces mixed frequency data into the field of wind speed forecasting and combines the merits of mixed-frequency models and artificial intelligence methods, is developed for wind speed forecasting. More specifically, the original wind speed data are preprocessed by an advanced data decomposition technique to effectively tackle the challenges caused by noise and capture the main characteristics that existed in the original data. Moreover, some artificial intelligence models and mixed-frequency models are designed as sub-models and employed to predict future wind speed changes; these models aim to make full use of the information existing in common frequency and mixed-frequency data. Furthermore, a new ensemble forecasting model is developed by combining the power of kernel-based extreme learning machine and multi-objective optimization to ensemble the results output by the sub-models. Various experiments and discussions are designed using four seasons of data, and the proposed model achieves excellent forecasting results. For example, the mean absolute percentage errors of the proposed model are 4.4286%, 6.6154%, 5.2749% and 3.8662% for wind speed forecastings during the four seasons, proving the superiority of the developed model and the innovations and contributions provided by this study from different perspectives.

1. Introduction

This section provides the motivation of this study; a literature review; and the research content, innovations and main contributions of the study.

1.1. Motivation

Energy consumption, caused by rapid economic development, has led to the global overutilization of nonrenewable resources, which has led to a significant rise in greenhouse gas emissions and irreversible negative effects on the environment. Low-carbon and renewable green energy is playing an increasingly irreplaceable role worldwide and can play an important role in environmental protection. Wind energy, as clean, sustainable, and renewable energy, is attracting worldwide attention [1] and is considered one of the practical alternatives to traditional fossil fuel. Recent studies have pointed out that 20% of the global electricity supply can be provided via wind energy in 2030 [2]. Wind power and wind speed have a cubic ratio [3], in which means that a small change in wind speed will produce a large amount of wind power. Therefore, wind speed has prime importance with respect to the generation of wind power.

However, the inherent instability of wind speed [4] brings great difficulties to the management of wind power systems. Therefore, how

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A novel machine learning-based electricity price forecasting model based on optimal model selection strategy

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ABSTRACT

Current electricity price forecasting models rely on only simple hybridizations of data preprocessing and optimization methods while ignoring the significance of adaptive data preprocessing and effective optimization and selection strategies to obtain optimal models that improve the forecasting performance. To solve these problems, this study develops an improved electricity price forecasting model that offers the advantages of adaptive data preprocessing, advanced optimization method, kernel-based model, and optimal model selection strategy. Specifically, the adaptive parameter-based variational mode decomposition technology is proposed to provide desirable data preprocessing results, and a leave-one-out optimization strategy based on the chaotic sine cosine algorithm is presented and applied to develop optimal kernel-based extreme learning machine models. In addition, a newly proposed optimal model selection strategy is applied to determine the developed model that provides the most desirable forecasting result. Numerical results show that the developed model's performance metrics were best, and the average values of mean absolute error, root mean square error, mean absolute percentage error, index of agreement, and Theil's inequality coefficient in four datasets are 0.912, 0.7607, 0.57225, 0.9997 and 0.0041, respectively, which imply that the developed model is a promising, applicable and effective electricity price forecasting technique in the real electricity market.

1. Introduction

Forecasting theory and methods play crucial roles in promoting economic social development, offering significant economic and social benefits and reduced related costs [1]. In the last few decades, research and applications of forecasting models have received much attention in many research fields. The electrical power system, which is one of the most complex of all economic systems, includes the generation, transmission, scheduling and consumption of electrical energy, which plays an important role in every field of social production [2]. The dynamic changes that occur inside power systems influence the power supply quality and can even threaten the power system's safety and stability. Therefore, studies on electrical power systems are important both from theoretical and applied viewpoints and require further research due to their large sizes and growing influences. In recent years, numerous studies focused on electrical power systems have been conducted [3], such as power system planning [4], wind speed and power forecasting [5–10], load forecasting [11–16], and energy demand and price modeling [17–20]. Note that research and application into forecasting theory and methods are of critical practical significance to power market management. Furthermore, in the context of power market liberalization and deregulation policy, electricity prices have become a cornerstone by which market participants construct bidding strategies, procurement plans and make other decisions [19]. Market participants who can

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Interval type-2 fuzzy programming method for risky multicriteria decision-making with heterogeneous relationship

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ABSTRACT

We propose a new interval type-2 fuzzy (IT2F) programming method for risky multicriteria decision-making (MCDM) problems with IT2F truth degrees, where the criteria exhibit a heterogeneous relationship and decision-makers behave according to bounded rationality. First, we develop a technique to calculate the Banzhaf-based overall perceived utility values of alternatives based on 2-additive fuzzy measures and regret theory. Subsequently, considering pairwise comparisons of alternatives with IT2F truth degrees, we define the Banzhaf-based IT2F risky consistency index (BIT2FRCI) and the Banzhaf-based IT2F risky inconsistency index (BIT2FRII). Next, to identify the optimal weights, an IT2F programming model is established based on the concept that BIT2FRII must be minimized and must not exceed the BIT2FRCI using a fixed IT2F set. Furthermore, we design an effective algorithm using an external archive-based constrained state transition algorithm to solve the established model. Accordingly, the ranking order of alternatives is derived using the Banzhaf-based overall perceived utility values. Experimental studies pertaining to investment selection problems demonstrate the state-of-the-art performance of the proposed method, that is, its strong capability in addressing risky MCDM problems.

1. Introduction

Multicriteria decision-making (MCDM) has been extensively applied to different fields, such as postgraduate course assessment [18], investment evaluation [13,19], research and development project selection [20], and comprehensive logistics distribution center location selection [17]. The traditional linear programming technique for multidimensional analysis of preference (LINMAP), which was proposed by Srinivasan and Schcker [31], iscurrently one of the most well-known MCDM approaches in modern decision theory because of its two advantages:

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A novel method based on probabilistic linguistic term sets and its application in ranking products through online ratings

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Abstract

In practical decision-making problems, the coexistence of several complex situations increases the difficulty for decision makers to make reasonable decision, such as attributes outnumber alternatives, heterogeneous relationships among multiple attributes, and individual risk tendency of decision maker. In view of the advantage of probabilistic linguistic term sets (PLTSs) in presenting qualitative information, a novel decision-making approach with PLTSs is constructed to deal with the above special situations simultaneously. To realize this goal, some basic models have been proposed. First of all, to truly reflect the importance of attributes from the heterogeneous relationships, a weight determination model with generalized Banzhaf values is developed to analyze the interaction between combinations of attributes. Then, for analyzing the individual risk tendency of decision maker, the generalized Banzhaf TODIM method with PLTSs is constructed. Moreover, based on the above research results, the generalized Banzhaf TODIM-QUALIFLEX method with PLTSs is developed to solve decision-making problems where the number of attributes exceeds the number of alternatives, the combinations of attributes are interacted with each other, and decision maker is affected by individual risk propensity. Lastly, smartphones selection through online ratings is a

Consistency- and consensus-based group decision-making method with incomplete probabilistic linguistic preference relations

Peide Liu, *Member, IEEE*, Peng Wang and Witold Pedrycz, *Fellow, IEEE*

***Abstract*—The use of incomplete probabilistic linguistic term sets (InPLTSs) can enrich the flexibility of qualitative decision-making information expression, especially in decision-making situations with high time pressure and insufficient knowledge. In this study, we develop a method for group decision-making (GDM) with incomplete probabilistic linguistic preference relations (InPLPRs), considering consistency and consensus simultaneously. First, to fully explore the ability of InPLTSs to express uncertain information, InPLTSs are specifically classified. Then, an expected multiplicative consistency of InPLPRs is introduced, which is conductive to estimating the missing information more accurately and effectively. Subsequently, considering the consensus of GDM problems, a consensus index, which considers the principle of majority and minority, is developed to measure the agreement degree among multiple individuals. Because individual InPLPRs may not all meet acceptable consistency after reaching consensus, a consistency- and consensus-improving mathematical programing model considering information distortion is presented. Then, to aggregate all individual preference relationships into a collective one, a reliability induced ordered weighted geometric operator is introduced, whose induced variable reliability is determined by the confidence degree and consistency index of individual preference relationships. Furthermore, a multi-phase algorithm with InPLPRs is developed to solve GDM problems. Finally, a numerical example about fire emergency decisions is presented to illustrate the applicability of the proposed method, and a detailed validity test and comparative analysis are conducted to highlight the advantages of the proposed method.**

***Index Terms*—Group decision-making; incomplete probabilistic linguistic preference relation; expected multiplicative consistency; consensus; mathematical programing model; induced ordered weighted geometric operator.**

Nomenclature

AHP	Analytic hierarchy process
BUM	Basic unit-interval monotonic
CPLTS	Complete probabilistic linguistic term set
CPLPR	Complete probabilistic linguistic preference relation
DLPR	Distribution linguistic preference relation
EV-CPLPR	Expected value-based complete probabilistic linguistic preference relationship
EHFLTS	Extended hesitant fuzzy linguistic term
GDM	Group decision-making
HFLT	Hesitant fuzzy linguistic term
HFLTS	Hesitant fuzzy linguistic term set
HFLPR	Hesitant fuzzy linguistic preference relation
InPLE	Incomplete probabilistic linguistic element
InPLTS	Incomplete probabilistic linguistic term set
InPLPR	Incomplete probabilistic linguistic preference relation
IOWG	Induced ordered weighted geometric
LDA	Linguistic distribution assessment
LT	Linguistic term
LTS	Linguistic term set
MLT-InPLTS	Missing LT in InPLTS
MP-InPLTS	Missing probability in InPLTS
OWG	Ordered weighted geometric
PD-HFLTS	Possibility distribution for HFLTS
PDM	Preference decision-making
PLPR	Probabilistic linguistic preference relation
PLTS	Probabilistic linguistic term set
PHFLTS	Proportional HFLTS
QGDD	Quantifier-guider dominance degree
R-IOWG	Reliability-IOWG

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I. Introduction

OWING to the increasing complexity of decision-making problems and the uncertainty of the decision-making environment, more experts are needed to participate in decision-making, thus GDM should be considered [1, 2]. Generally speaking, the evaluation of an object can be performed in many ways, e.g., through multi-attribute decision-making, which involves evaluating multiple attributes of an object and then obtaining a comprehensive evaluation result based on the values of each attribute [3, 4]. However, in some decision-making situations with high time pressure and insufficient knowledge, PDM is more effective. Through an AHP, Saaty [5] reported preference relation, which is a form of pairwise comparison between alternatives that allows experts to generate reasonable preference information about each object compared based on specific criteria. Preference relation is highly consistent with people's evaluation habits and has become the most common evaluation tool for presenting judgment information in decision-making.

The research of preference relationship in GDM mainly focuses on consistency and consensus. Consistency research involves consistency tests and improvement processes. In practical decision-making, it is very difficult to obtain a preference decision matrix that represents a completely reasonable logical relationship. Therefore, a consistency test is the first and key step in the decision-making process. At present, the most commonly used consistency measures are additive consistency [1, 6-8] and multiplicative consistency [9-11]. In addition, because the inconsistent judgment matrix seriously restricts the accuracy of the decision results, the improvement mechanism of consistency has also attracted considerable attention [11-13]. There are two typical methods to improve the consistency, namely iterative and optimization adjustment. For instance, Zhou & Xu [13] introduced an iterative optimization algorithm to improve the consistency

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A weighting model based on best–worst method and its application for environmental performance evaluation

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ABSTRACT

The analytic hierarchy process (AHP) is widely used as a multi-criteria decision-making method in practical applications. Several researchers have expanded the AHP method to D numbers AHP (D-AHP) to apply AHP to an uncertain decision-making environment. D numbers is an extension of the Dempster–Shafer (D–S) theory, which overcomes the shortcomings of the D–S theory and can effectively express uncertain information. With the deepening of research on the AHP method, the best–worst method (BWM) was proposed as an improvement to the AHP method. The BWM can lower the inconsistency in results and reduce the number of required pairwise comparisons. Although some researchers have extended the BWM method to an uncertain environment and proposed fuzzy BWM methods, these methods cannot handle some special situations, such as when the subjective evaluations of experts are conflicting or altogether missing. To apply the BWM method to these special situations, this study suggests combining the BWM with D numbers and proposes D numbers BWM (D-BWM) weighting model. First of all, we discuss D numbers extended fuzzy preference relations (DNFPRs). Afterwards, we design an algorithm to select the best and worst criteria based on the DNFPRs by calculating the out-degrees and in-degrees. Furthermore, we develop a linear programming model to derive the weights of criteria, and then propose a consistency ratio to check the reliability of the derived results. The experimental results show that the D-BWM method is more suitable for realistic decision-making because of its simplicity and sensitivity to subjective information. Finally, the proposed method is applied to evaluate the environmental performances of 30 provincial administrative regions of China.

1. Introduction

Multi-criteria decision-making (MCDM) is the process of evaluating situations and analyzing multiple conflicting assessments to arrive at a decision. It is a significant part of the decision-making theory [1]. Based on the discrete or continuous solution space, MCDM is usually divided into multi-attribute decision-making (MADM) and multi-objective decision-making. In this study, we used MCDM to represent MADM for convenience and practicality. Owing to the evaluation mechanism characteristics of MCDM, it is widely applicable to real decision-making environments such as in management [2], transportation [3], investment [4], and other fields [5,6]. Several MCDM methods have been researched and expanded, such as the analytic hierarchy process (AHP) [7,8] and the technique for order of preference by similarity to ideal solution (TOPSIS) method [9] for different decision situations. Among the MCDM methods, AHP is widely used owing to its applicability and operability in practical applications [10]. AHP, proposed by Saaty [7,8], is based on pairwise comparisons and is widely used in practical management environments such as public transport service development [11], urban planning [12,13] and urban sustainability assessment [14]. Furthermore, to overcome the environmental uncertainty in some practical decisions and the ambiguity of human consciousness, fuzzy sets [15], intuitionistic fuzzy sets [16], Pythagorean fuzzy sets [17], hesitant fuzzy sets [18], interval type-2 hesitant fuzzy sets [19] are proposed. Some researchers have expanded the classical AHP to the fuzzy AHP method with the aid of these fuzzy sets. Fuzzy AHP [20], intuitionistic fuzzy AHP [21], Pythagorean fuzzy AHP [22] and hesitant fuzzy AHP [23] are proposed to solve decision problems in different situations. These fuzzy AHP methods have a better comprehensive structure than the traditional AHP because these methods combine quantitative and qualitative criteria. For example, Zyoud et al. [20] applied the fuzzy AHP to study how to reduce water loss, and Liao and Xu [21] studied the consistency of AHP preference relationships in intuitionistic fuzzy environments. Ilbahar et al. [22] combined risk assessment with fuzzy AHP to evaluate occupational health.

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The new extension of the MULTIMOORA method for sustainable supplier selection with intuitionistic linguistic rough numbers

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Abstract: Due to the increasing awareness of environmental and social issues, sustainable supplier selection (SSS) becomes an important problem. In order to scientifically evaluation the SSS, the aim of this paper is to develop a novel SSS method considering the robustness and relationship among experts. Firstly, a novel concept of intuitionistic linguistic rough numbers (ILRNs) is proposed to accurately express the opinions of expert groups for SSS and to consider the interactive relationship among experts. Then we present a process to construct ILRNs and introduce the arithmetic operations, distance measure, correlation measure, ranking rules, aggregation operators, and some corresponding properties. In addition, based on the correlation coefficients between attributes, we introduce a weight determining method. Moreover, considering the robustness of the ranking method, the multiplicative Multi-objective Optimization by Ratio Analysis (MULTIMOORA) is enhanced by developing a new aggregated model and the improved Borda rule, which can consider both the subordinate utility values and ranks, and an intuitionistic linguistic MULTIMOORA method and an intuitionistic linguistic rough MULTIMOORA method are developed respectively. Finally, a real case of a shared power bank SSS is conducted to illustrate the application of the proposed method, and a comparison is performed to explain the superiority and feasibility of the proposed method.

Keywords: Sustainable supplier selection; intuitionistic linguistic rough number; MULTIMOORA; Borda rule.

1. Introduction

Due to environmental pollution, resource depletion, and fierce competition, countries, organizations, and academic and professional institutes have reached a consensus on sustainable development [1]. However, the development of methods to balance the economic benefits and sustainable development has already become a challenging task for contemporary enterprises in the course of sustainable supply chain management (SSCM) [2,3]. Sustainable supplier selection (SSS) is considered the most significant issue in SSCM for advancing the close cooperative relationship between the purchaser and supplier [1,2,3,4,5].

Economic, environment and social attributes are involved in the evaluation and selection of an ideal sustainable supplier [6]. Consequently, SSS is regarded as a multi-attribute decision-making (MADM) process. The purpose is to select the optimal portfolio of sustainable suppliers among a set of alternatives. The recent literature reviews from Govindan et al. [4] and Rajeev et al. [5] show that MADM is one of the most common methods applied to SSS. Yu et al. [7] introduced a multi-attribute group decision-making (MAGDM) SSS method. Mohammed et al. [8] proposed a hybrid MCDM multi-objective optimization method for SSS and order allocation. Additionally, the vast majority of the

Multicriteria Decision Making With Incomplete Weights Based on 2-D Uncertain Linguistic Choquet Integral Operators

Peide Liu, Shyi-Ming Chen, *Fellow, IEEE*, and Guolin Tang

***Abstract*—In regard to multicriteria decision making (MCDM) problems where the values of the criteria are expressed by 2-D uncertain linguistic variables (2DULVs), where the criteria are interactive and the criteria weights are incompletely known, two novel MCDM methods are proposed in this paper. First, we offer some novel operational laws of 2DULVs, which can avoid the operational results exceeding the boundary of linguistic term sets. Then, we propose four operators to capture the interactions over the criteria, namely, the 2-D uncertain linguistic Choquet averaging (2DULCA) operator, the 2-D uncertain linguistic Choquet geometric (2DULCG) operator, the Shapley 2DULCA (S2DULCA) operator, and the Shapley 2DULCG (S2DULCG) operator. In addition, we establish the models based on the maximization deviation approach and the Shapley function to get the criteria weights. Finally, we propose two novel MCDM methods under 2-D uncertain linguistic environments, where four examples are used to explain the created MCDM methods. Comparative experimental results are presented to highlight the superiorities of the created approaches.**

***Index Terms*—2-D uncertain linguistic variable (2DULV), Choquet integral, fuzzy measure (FM), generalized Shapley index (GSI), multicriteria decision making.**

I. Introduction

SINCE Zadeh [1] presented the notion of linguistic variables (LVs), the study on multicriteria decision making (MCDM) with linguistic information or its extensions has gained widespread attention [2]–[7]. Zhang and Xing [2] extended the viseKriterijumska optimizacija i kompromisno resenje (VIKOR) approach to a probabilistic linguistic environment for MCDM. Wan *et al.* [3] extended the elimination et choice translating reality II (ELECTRE II) method to handle interval 2-tuple linguistic (2TL) MCDM problems. Beg and Rashid [4] presented a fuzzy technique for order preference by similarity to ideal solution (TOPSIS) method for dealing with hesitant 2TL MCDM problems. It is obvious that the VIKOR method, the ELECTRE II approach, and the TOPSIS method can deal with fuzzy linguistic MCDM problems. Although they can provide the ranking of alternatives, they cannot provide comprehensive criteria values of alternatives. The MCDM methods based on fuzzy linguistic aggregation operators not only provide the ranking of alternatives but also provide comprehensive criteria values of alternatives, which have widely been investigated recently. For instance, Liu *et al.* [5] explored a series of interval grey uncertain linguistic aggregation operators, Xu [6] proposed some triangular fuzzy linguistic aggregation operators, and Ju *et al.* [7] investigated fuzzy trapezoid fuzzy 2TL aggregation operators, which have been utilized to handle MCDM problems.

The MCDM methods in [2]–[7] with fuzzy linguistic information are developed so perfectly that it seems all fuzzy linguistic MCDM problems can be well solved. But even so, there are three issues that need to be pointed out.

1) The traditional fuzzy linguistic operations are not closed, which could cause granularity problems [8] and logical problems [8]. For example, let $\bar{S} = \{s_t | t = 0, 1, \ldots, 5\}$ be a linguistic term set (LTS), and let $[s_2, s_4]$ and $[s_3, s_5]$ be two uncertain LVs (ULVs); then according to operations of ULVs [9], we can obtain $[s_2, s_4] \otimes [s_3, s_5] = [s_6, s_{16}]$. It is obvious that this result exceeds the boundary of $\bar{S}$.
2) For some fuzzy linguistic MCDM problems, for instance, the blind review of journal articles and the assessment on the projects, the decision makers (DMs) not only need to provide the assessment results of the criteria by utilizing the linguistic information, such as "bad," "good," and "very good," but also need to provide their reliability judgments of these evaluation results by utilizing the linguistic information, such as "very unfamiliar," "unfamiliar," and "extremely familiar." The traditional fuzzy linguistic methods in [2]–[7] cannot solve this issue, that is, they cannot describe the linguistic information about the dependability of a DM's subjective evaluation.

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Multiple-Attribute Group Decision-Making Based on q-Rung Orthopair Fuzzy Power Maclaurin Symmetric Mean Operators

Peide Liu, Shyi-Ming Chen, *Fellow, IEEE*, and Peng Wang

***Abstract*—To be able to describe more complex fuzzy uncertainty information effectively, the concept of *q*-rung orthopair fuzzy sets (*q*-ROFSs) was first proposed by Yager. The *q*-ROFSs can dynamically adjust the range of indication of decision information by changing a parameter *q* based on the different hesitation degree from the decision-makers, where $q \geq 1$, so they outperform the traditional intuitionistic fuzzy sets and Pythagorean fuzzy sets. In real decision-making problems, there is often an interaction phenomenon between attributes. For aggregating these complex fuzzy information, the Maclaurin symmetric mean (MSM) operator is more superior by considering interrelationships among attributes. In addition, the power average (PA) operator can reduce the effects of extreme evaluating data from some experts with prejudice. In this paper, we introduce the PA operator and the MSM operator based on *q*-rung orthopair fuzzy numbers (*q*-ROFNs). Then, we put forward the *q*-rung orthopair fuzzy power MSM (*q*-ROFPMSM) operator and the *q*-rung orthopair fuzzy power weighed MSM (*q*-ROFPWMSM) operator of *q*-ROFNs and present some of their properties. Finally, we present a novel multiple-attribute group decision-making (MAGDM) method based on the *q*-ROFPWA and the *q*-ROFPWMSM operators. The experimental results show that the novel MAGDM method outperforms the existing MAGDM methods for dealing with MAGDM problems.**

***Index Terms*—Maclaurin symmetric mean (MSM) operator, multiple-attribute group decision-making (MAGDM), power average (PA) operator, *q*-rung orthopair fuzzy sets (*q*-ROFSs).**

I. Introduction

MULTIPLE-ATTRIBUTE group decision-making (MAGDM) problems can be regarded as a process which ranks alternatives according to the evaluating attribute values of the alternatives from multiple experts and they have been extensively studied by more and more scholars [5], [22], [44]. MAGDM is a typical and important decision problem. In the broad sense, the decision problems, especially group decision-making (GDM) problems, contain many types, which can be divided from the way of information expression and the way of dealing with problems. The most commonly used definition of GDM problems is based on the four-field notation [3]. The first field X is the evaluation value, which is represented by x_i, its domain is ("crisp" and "vague"); the second field CX is the degree of confidence in x_i, which is represented by α, its domain is a probability number within (0, 1]; the third field W is the degree of importance of the expert, i.e., the weight of the expert, which is represented by w_k, its domain is (crisp and vague); and the fourth field CW is the degree of confidence in w_k, which is represented by β, its domain is a probability number within (0, 1]. Based on this notation, most decision situations (S) can be expressed as: $S = [\text{crisp/vague}, \alpha, \text{crisp/vague}, \beta]$. In the existing literatures, many studies have focused on the MAGDM problems based on the situation of [vague, 1, crisp, 1], and indeed, the research contributions and concerns of this paper are based on this problem. For MAGDM problems in fuzzy environments, the description of evaluation information, i.e., the first field X, is crucial, so we need to consider how to effectively express evaluating attribute values of alternatives. Due to the fuzziness of human cognition and the complexity of decision environments, exact values or linguistic variables are not enough to express uncertainty information. In order to deal with this situation, Atanassov [1], [2] first introduced the theory intuitionistic fuzzy sets (IFSs), which is extended from the theory of fuzzy sets (FSs) [42]. The advantage of IFSs is that they can express fuzzy information by a membership degree (MD), a nonmembership degree (NMD), and a hesitancy degree, respectively. The theory of IFSs began to be studied by many researchers and has widely been applied to the fields of multiple-attribute decision-making (MADM) and MAGDM. The main results can be divided into three aspects.

1) *The Basic Theoretical Results of Intuitionistic Fuzzy Numbers (IFNs):* Such as some operation rules [8], some distance measures [6], [31], some similarity measures [4], [24], the information entropy [11], etc.
2) *The Extended Decision Evaluation Methods Based on IFNs:* Such as the technique for order preference by similarity to an ideal solution (TOPSIS) method

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基于证据推理和广义 Shapley 值的扩展概率语言多属性群决策方法

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摘 要:扩展概率语言词集通过语言变量概率分布的调整能够转化为多种语言信息表示模型,是语言变量、不确定语言信息、扩展犹豫模糊语言词集、分布语言评估信息、概率语言词集等的一般化,具有较强的通用性和实用性,是处理不确定性信息的重要工具。鉴于此,本文针对扩展概率语言环境下的多属性群决策问题,提出基于证据推理和广义 Shapley 值的多属性群决策方法。首先,提出扩展概率语言词集的定义和相关基础理论。其次,将广义 Shapley 值和证据推理相结合用于专家信息融合,并将广义 Shapley 值和 TODIM 方法相结合用于备选方案排序。再次,提出基于灰色关联法的权重确定模型来处理专家/属性权重部分未知的情况。最后,以绿色供应商选择为例进行分析,通过对比分析验证所提方法的有效性和优越性。

关键词:多属性群决策;扩展概率语言词集;证据推理;TODIM 方法;广义 Shapley 值
中图分类号:C934 **文献标识码**:A

1 引言

随着大数据、云计算等科学技术的发展,越来越多的决策者参与到现实重大决策问题中。以北京市公共交通价格调整事件为例,北京市发展改革委和交通委就价格改革向社会公众征求意见,全市市民通过多种方式积极参与此次决策问题,此类包含众多决策者参与的决策问题被称为大群体决策问题。现实生活中还存在着大量的大群体决策问题,例如突发事件应急决策管理、城市地铁选址和路线规划、政府政策调整等。这促使大群体决策问题成为当今的研究热点。

由于决策对象的复杂性以及决策者思维的模糊性,决策者的真实体会难以用实数进行刻画。其尤是针对决策者的定性偏好信息,语言变量作为一种定性信息描述工具能够恰当地描述决策者的偏好信息。大群体决策中,决策者依据各自的利益可以被分为多个子群体,子群体中决策者给出的信息量巨大,如何将各个子群体中决策者给出的信息进行完整的呈现是一个值得探讨的问题。基于此,Wang Hai 将多个决策者给出的语言变量信息进行汇总融合[13],提出了扩展犹豫模糊语言集的概念。Zhang Guiqing 等考虑了每个语言变量在所有给出的语言变量中的支持度,从而定义了包含语言变量和相关支持度的分布语言评价集[12]。Chen Zhensong 等提出了比例犹豫模糊语言词集的概念,它对每个语言变量提供了比例分量信息,其数学表达形式和分布语言评估信息相同,但潜在含义不同,可以看作是执行分布语言评估信息的特殊方法[23]。在收集决策者给出评价信息的过程中存在部分决策者未给出评价信息的情况,基于此,Pang Qi 等提出了概率语言词集的概念用于描述评价信息过程中存在部分信息缺失的情况,其要求收集到的语言变量的概率和小于等于 1[24]。然而,现实情况还存在一个决策者给出多个语言变量的情况,这会导致所有语言变量的概率和大于 1。然而,上述语言信息表示模型都不能描述此类情况,因此本文探寻了一种新的信息表示模型,对语言变量的概率放宽限制,提出了扩展概率语言词集,其能够表示概率和大于 1、小于 1 和等于

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