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An integrated expert system for fast disaster assessment

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ABSTRACT

Most of the existing disaster assessment models are based on single method, such as expert system, or one of the multi-criteria decision making (MCDM) methods. This paper proposes an efficient disaster assessment expert system, which integrates fuzzy logic, survey questionnaire, Delphi method and MCDM methods. Two simulation experiments on typhoon and earthquake are introduced to validate the integrated expert system. The satisfaction degrees of the proposed model in both cases are 75% and 74.5%, respectively, which are close to the ideal rate (78%) of the proposed model. The experimental results show that the proposed expert system is not only efficient, fast and accurate, but also robust through self-adaptive study and has strong adaptability to different environments.

1. Introduction

There are different forms of natural disasters, including typhoon, hurricanes, heavy rains, volcanic explosion, sea level rise, flooding, drought and earthquake etc. These natural disasters have caused significant economic, social, financial, property and infrastructure damages and even tragic loss of human lives each year worldwide. For instance, in 2007, there were approximately 450 of these natural disasters worldwide, affecting around 211 million people, and causing economic losses amounting to 74 billion US dollars [39]. According to UN's estimation, during the period from 2000 to 2009, 4000 disasters were recorded which caused an estimated economic loss of US$960 billion worldwide [34].

In recent years, an increasing number of studies focus on disaster assessment, one of the most important subjects in disaster research [49,51,28,44], and a variety of models and techniques have been extensively developed for disaster assessment, including geographic information systems (GIS), expert system (ES), multi criteria decision making (MCDM), and fuzzy theory (FT). For example, Zerger and Smith [56] used GIS to deal with temporal data for real-time disaster decision support. Wei et al. [49] presented a data envelopment analysis (DEA)-based model for analysis of regional vulnerability to natural disasters in China to improve the traditional method. Qin et al. [33] developed an MCDM-based expert system to tackle the interrelationships between the climate change and the adaptation policies in terms of water resources management in the Georgia Basin, Canada. Jiang et al. [19] evaluated the damage of floods by fuzzy logic. Tinguaro Rodríguez et al. [43] applied a data-based, two-level knowledge decision support system (DSS) prototype to support humanitarian NGOs in response to natural disaster. Tang and Wen [42] designed a disaster assessment system based on the platform of a global information system (GIS) and artificial intelligence (AI).

Among the proposed models and techniques, MCDM techniques are popular for various decision making and evaluation. Since the early 1970s, MCDM techniques have been developed into many forms and been employed for a wide range of different case studies. MCDM techniques can be used to identify desired measures among a variety of alternatives through analyzing multiple criteria, by which the strengths and weaknesses of various adaptation options are evaluated [15]. Meanwhile, the optimal solution among all of the feasible alternatives can be ranked and recommended by MCDM techniques in terms of the related tangible and intangible multiple decision criteria [40]. Since disaster assessment usually involves tangible and intangible multiple criteria, MCDM methods therefore are widely used for disaster assessment.

Expert systems are important tools in risk control and disaster management systems [13]. Without expert systems, it would consume huge amounts of time and cost for the decision makers to collect experts' opinions and suggestions to make final decisions. However, the collected data cannot be processed automatically by ES alone if there is large amount of data [48]. In addition, the involved factors of disasters are normally intangible, and the judgments made by experts are usually imprecise and uncertain, Fuzzy theory is therefore used to describe and deal with the imprecise and uncertain data in the process of disaster assessment and decision making. Therefore, in order to assess the disaster effectively and quickly whilst avoiding the preference

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influence caused by single method [32], it is necessary to apply several assessment techniques simultaneously to deal with the disaster data [30].

The goal of this paper is to propose an integrated expert system with fuzzy logic, Delphi method and MCDM methods for fast disaster assessment. In the integrated expert system, heterogeneous data with different time series is integrated by fuzzy logic and five MCDM methods, in which fuzzy logic is used to deal with the imprecise and uncertain survey data, while five MCDM methods are used to compute the disaster data with time series and synthesize the computed results. The Delphi method with four-round questionnaire survey is used to obtain the weights of attributes. In the process of decision making, decision makers may move back and forth between different modules of the expert system so the decision model can be revised to fit with experts' opinions.

The remaining of this paper is organized as follows: Section 2 presents the related methods, the questionnaire and the advantage of ensemble, respectively. The flow chat of the proposed integrated expert system is proposed in Section 3. The experimental results are presented and discussed in Section 4. After the experiment, the proposed expert system is evaluated by another questionnaire. Besides, the sensitivity analysis of experimental results is also discussed in this section. Furthermore, the applicability of the proposed model is tested by two synthetic datasets on typhoon and earthquake through simulation experiment in Section 5. The last section concludes the paper.

2. Related methods description

In the integrated expert system, the fuzzy theory is introduced to process the imprecise and uncertain survey data obtained from the experts' feedback of questionnaire. Five recommended MCDM methods, including AHP, PROMETHEE II, TOPSIS, GRA and OWA, are used to process the disaster data, in which the first four MCDM methods are employed for parallel computing, OWA is used to synthesize the computing results by the other four MCDM methods. In the following, the related five MCDM methods and fuzzy theory are briefly described; the questionnaire and the advantage of ensemble are also illustrated in this section.

2.1. Fuzzy Delphi method

Fuzzy numbers are usually used to represent the preference relation of the alternatives and the criteria when the pertinent data and the sequences of possible actions are not precisely known [22]. Additionally, in many real world issues, expert's judgments cannot be properly reflected in quantitative terms, much human knowledge is usually vague and imprecise [55]. Therefore, the fuzzy weights are introduced to make full use of experts' experience and suggestion to maximize the effectiveness of experts' system. The fuzzy concepts have been incorporated into several expert systems, such as Cadiag-2' and Fault which are purposely built from a high-level language for a specific domain of application [1]. Besides, most of today's commercial expert-system building tools use certainty or confidence factors to handle uncertainties in the knowledge or data [20].

The traditional Delphi Technique was originally developed by Dalkey and Helmer [11] in the late 1960s as a forecasting methodology to obtain the most reliable consensus of opinion of a group of experts without necessarily bringing them together face to face. However, since the repeated rounds of Delphi process bears more cost and time as well as low response rate in successive rounds and low convergence expert opinions, Murray et al. [27] initially proposed to integrate the fuzzy set theory with Delphi method, and named the fuzzy Delphi method to capture the imprecise nature of experts' opinion. Thereafter, Ishikawa et al. [18] further extended the fuzzy Delphi method and developed max–min and fuzzy integration algorithms to predict the prevalence of computers in the future. Hsu and Yang [16] applied triangular fuzzy number to encompass expert opinions and establish the fuzzy Delphi method. Fuzzy Delphi method requires only a small number of samples and the derived results are objective and reasonable. Not only it saves time and cost required for collecting expert opinions, but also experts' opinions will also be sufficiently expressed without being distorted [18].

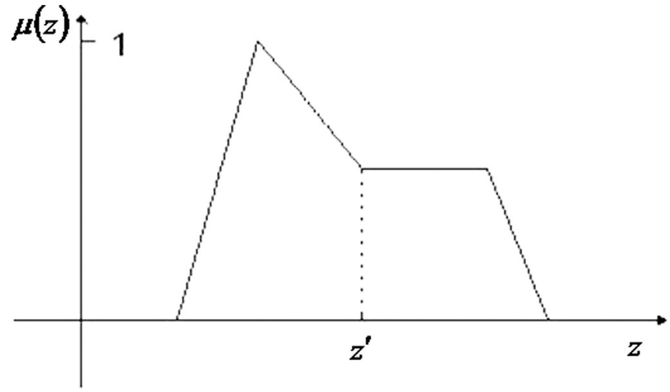

Fig. 1. The relation graph of the fuzzy membership functions.

In this paper, the fuzzy Delphi method is used to obtain the attribute weights and the weights of four MCDM methods, all the fuzzy data from the questionnaires are processed with fuzzy statistics and centroid defuzzification method. The fuzzy statistics is evolved from the classic statistics, and the calculation procedures of fuzzy statistics correspond with the random pattern of probability and statistics [25,21], while the centroid defuzzification [45,47] is an adaptive defuzzification method and is one of the most convenient and outstanding methods. The centroid defuzzification is used to deal with fuzzy membership function $\mu(z)$ by an algebraic integral, which is defined as Z and shown below. The relation graph of the fuzzy membership function is shown in Fig. 1, where z' denotes a virtual centroid.

$$Z = \int \mu(z) \times z dz / \int \mu(z) dz$$

Fuzzy statistics and centroid method are combined efficiently to transform the experts' knowledge to the quantitative values, which can further be handled by the recommended MCDM methods.

2.2. Dynamic comprehensive analysis

In real world evaluation, assessors are sometimes facing such problems that there are a large number of two-dimensional time-series data for the same evaluation problem as time passes and data accumulates, these data series are called multidimensional time series, and these problems are defined as dynamic comprehensive evaluation problems. Therefore, the key of dynamic comprehensive evaluation problems is to decrease dimensions, that is, turn multi-dimensional time series into two dimensional data.

Guo et al. [14] proposed a twice-weighted comprehensive analysis and applied the time ordered weighted averaging (TOWA) operator and the time ordered weighted geometric averaging (TOWGA) operator to decease dimensions and aggregate data. Dynamic comprehensive analysis is one kind of decision making and assessment method, including the following three steps: (1) Calculate the normalized matrix; (2) determine the weights of all assessment indices; (3) calculate time weighting vectors. Time weighting vectors (called T values) are used to reflect the