Decision Support Systems 51 (2011) 307–315

Contents lists available at ScienceDirect

Decision Support Systems

journal homepage: www.elsevier.com/locate/dss

A distance-based group decision-making methodology for multi-person multi-criteria emergency decision support

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ARTICLE INFO

Available online 25 November 2010

Keywords:
Multi-criteria decision-making
Group decision-making
Group consensus
Emergency management
Emergency decision support

ABSTRACT

In this paper, a distance-based group decision-making (GDM) methodology is proposed to solve unconventional multi-person multi-criteria emergency decision-making problems. In this model, some decision-makers are first identified to formulate a group decision-making framework. Then a standard multi-criteria decision-making (MCDM) process is performed on specific decision-making problems and different decision results are obtained from different decision-makers. Finally, these different decision results are aggregated into a group consensus to support the final decision-making. For illustration and verification purposes, a numerical example and a practical unconventional emergency decision case are presented. Experimental results obtained demonstrate that the proposed distance-based multi-criteria GDM methodology can improve decision-making objectivity and emergency management effectiveness.

1. Introduction

Unconventional emergency events, such as earthquakes and hurricanes, often lead to unexpected catastrophic consequences [5]. When such devastating incidents occur, emergency planning and management play a crucial role in reduction and mitigation of their effects. In the emergency planning and management, there are a great many emergency decision-making problems that need to be solved, to handle effects of the destructive events. Usually, an emergency decision has the following two distinct features. First, an emergency decision must often be made in a short period of time using partial or incomplete information, especially in the early stages of the disaster occurrence. Accordingly emergence group decision-making (GDM) is an intractable task, particularly when handling some unconventional high impact emergency events. Second, these decisions may have potentially serious outcomes. In many situations, a wrong decision could result in deadly consequences [13]. In view of the unique characteristics of emergency decisions, using group decision support systems (GDSS) [6,8,9] to handle emergency decision problems could be extremely valuable.

Some previous studies [13,15,27] also revealed that the GDSS has great potential applications in modern emergency planning and management. For example, Levy and Taji [13] proposed a group analytic network process (GANP) to construct a GDSS to support hazard planning and emergency management under incomplete information. In their study, a typical unconventional emergency event, a chemical spill in the city of Brandon, Manitoba is simulated. With application in evacuation and shelter-in-place decisions, it is shown that the proposed GANP model improves emergency management effectiveness, decision transparency, and user satisfaction [13]. Zografos et al. [27] presented a methodological framework for developing a hazardous material emergency response (HAMER) decision support system (DSS) to manage emergency response operations for large-scale industrial accidents in Western Attica, Greece. Similarly, Mendonca et al. [15] designed a gaming simulation to assess GDSS for emergency response in emergency management.

Although these existing studies have shown that GDSS can improve emergency management effectiveness and decision transparency due to the fact that it can integrate group wisdom of multiple decision-makers into one group wisdom, there are two key issues that are apparently not solved well by GDSS. On the one hand, in the process of multi-criteria decision-making (MCDM), determining a set of suitable weights for multiple evaluation criteria is often considered to be a very difficult task. In the existing literature, many researchers usually set some arbitrary weights for each criterion to solve specified decision-making problems in terms of subjective judgments of decision-makers. But such a processing method will add the subjectivity and thus reducing the decision accuracy, sometimes leading to wrong decision results. On the other hand, in the process of using GDM, evolving an effective group consensus out of different judgments from different decision-makers, is still an unsolved issue in the previous studies.

Inspired by the GDSS, this study attempts to propose a distance-based multi-criteria group decision-making (GDM) methodology to support multi-person emergency decision problems. As is known, GDM is one of the most active research fields within MCDM [3]. In

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doi:10.1016/j.dss.2010.11.024

GDM, group members (i.e., decision-makers) first make their own judgments on the same decision problem independently, i.e. decision actions and alternatives, based on multiple evaluation criteria. These judgments from different decision-makers are then aggregated into a group consensus to support the final decision. Different from previous studies, this study tries to give an effective solution to the two unresolved issues, and to construct a distance-based multi-criteria GDM methodology for multi-person emergency decision support.

Generally, the proposed distance-based multi-criteria GDM methodology is comprised of three stages. In the first stage, some decision-makers (DMs) are first identified to formulate a GDM framework. Then a standard MCDM process is performed on the specific decision-making problems, and accordingly different decision results are obtained from different decision-makers in the second stage. In the third stage, these different decision results are aggregated into a group consensus to support the final decision. The main purpose of this study is to propose a new distance-based multi-criteria GDM model to support unconventional emergency decision-making problems. Using the proposed distance-based GDM model, many practical emergency decision-making problems can be solved effectively. For these real-world problems, decisions are made on the basis of a set of pre-defined criteria. Therefore, the proposed distance-based multi-criteria GDM methodology is suitable for solving these multi-person emergency decision-making problems.

The main contribution of this study is that a new distance-based multi-criteria GDM methodology is proposed to support unconventional emergency decisions, by providing a rational solution to the two unresolved key issues. Compared with traditional GDM methods, our proposed distance-based multi-criteria GDM model has three distinct characteristics. First, the decision-makers' judgments/evaluations are made on the basis of a set of criteria to formulate a multi-person multi-criteria GDM framework. This makes the decision results more objective than traditional single-person MCDM methods [10,11,14,16,17]. Second, the weights of evaluation criteria are determined based upon the data itself, thus reducing decision bias and adding the objectiveness to the proposed GDM methodology. Finally, different from previous subjective methods and traditional time-consuming iterative procedures, this paper proposes a fast optimization technique to integrate the different decision opinions, and to make the aggregation of different decision opinions simple.

The main purpose of the proposed multi-criteria GDM methodology is to improve decision accuracy, and to enhance decision transparency and thus to increase decision effectiveness. The rest of this paper is organized as follows. In Section 2, the proposed distance-based multi-criteria GDM methodology is described in detail. For illustration and verification purposes, Section 3 presents a numerical example and a practical emergency decision case to illustrate the implementation process, and to verify the effectiveness of the proposed distance-based multi-criteria GDM methodology. Finally, some concluding remarks are drawn in Section 4.

2. Formulation of distance-based multi-criteria GDM methodology

In this section, a general framework for multi-criteria GDM methodology is first presented. Then some main procedures or steps involved in the proposed distance-based multi-criteria GDM methodology are described in detail. Finally a summary for distance-based multi-criteria GDM methodology is given.

2.1. General framework for multi-criteria GDM methodology

In this study, a general multi-criteria GDM methodology framework is proposed for complex and multi-faceted decision-making problems. In order to help readers' understand multi-criteria GDM problems, a general form of multi-criteria GDM problem is shown in Table 1.

In Table 1, $(C_1, C_2, \cdots, C_m)$ denotes a number of evaluation criteria or evaluation attributes, $(A_1, A_2, \cdots, A_n)$ represents a set of alternatives or actions, $(DM_1, DM_2, \cdots, DM_p)$ is a group of decision-makers and $U_k(C_j(A_i))(i = 1,2,\cdots,n; j = 1,2,\cdots,m; k = 1,2,\cdots,p)$ denotes the utility value (evaluation value) of the ith alternative under the jth evaluation criterion in terms of the judgment of the kth decision-maker. The main feature of the multi-criteria GDM framework for solving decision-making problems is to formulate a comprehensive ordering/ranking mechanism for the given alternatives, based on a set of specified evaluation criteria and a group of decision-makers. To realize this, a general framework for multi-person multi-criteria GDM methodology is proposed, as shown in Fig. 1.

As can be seen from Fig. 1, we can find that the proposed multi-criteria GDM methodology consists of three main procedures: identification of group decision-makers, implementation of standard MCDM process for each decision-maker and formulation of group consensus, which are elaborated in the following subsections.

2.2. Identification of group decision-makers in GDM environment

In GDM environment, identification of members of the group decision-makers is an extremely important step as only competent decision-makers can effectively make eligible decisions based on a set of specified evaluation criteria; incompetent decision-makers can lead to some unexpected decision results.

Usually, multiple domain experts and important leaders from different fields can form a decision group to solve specified decision-making problems. In particularly, when we try to solve some complex and important decision-making problems, the decisions are often made by a decision group not only because of the problem complexity but also because of wider implications of the decision in terms of responsibility. For example, in the process of solving some unconventional emergency event (e.g., earthquake) decision-making problems, some experts from seismology, geology, meteorology and catastrophology, as well as officers from government departments should be included in the decision group. In order to form an effective decision group, the GDM manager or moderator, in most situations, is required to have abundant knowledge of GDM and have the capability of identifying and selecting some suitable experts in specified areas. In this way, GDM environment can be constructed and GDM consensus can be formed effectively.

2.3. Implementation of standard MCDM process

For a specified decision problem or decision alternative, different decision-makers usually give different estimations or judgments over a set of evaluation criteria $C = (C_1, C_2, \cdots, C_m)$. That is, a standard MCDM process is implemented for a specified decision alternative and a set of evaluation criteria after a suitable decision group is formed.

MCDM is a well-known branch of a general class of operations research (OR) models, which deal with a set of decision alternatives in terms of a number of evaluation criteria. In existing studies, there are a

Table 1
A general form of multi-criteria GDM problem.

Alternatives	DM_1			.....	DM_p		
	C_1	...	C_m	$C_1 \ldots C_m$	C_1	...	C_m
A_1	$U_1(C_1(A_1))$	...	$U_1(C_m(A_1))$	...	$U_p(C_1(A_1))$	...	$U_p(C_m(A_1))$
...	...	...	...	...	...	...	...
A_n	$U_1(C_1(A_n))$	...	$U_1(C_m(A_n))$	...	$U_p(C_1(A_n))$	...	$U_p(C_m(A_n))$