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Group decision support for hazards planning and emergency management: A Group Analytic Network Process (GANP) approach

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Abstract

Advances in the Group Analytic Network Process (GANP) are discussed to support hazards planning and emergency management under incomplete information. A GANP multi-criteria Decision Support System (DSS) is put forth that uses quadratic mathematical programming and interval preference information. Civil defense and emergency managers use the proposed DSS in emergency exercise to select among evacuation and "shelter-in-place" alternatives. It is shown that the proposed GANP architecture can improve decision-making transparency, emergency management effectiveness, and user satisfaction.

Keywords: Group decision support; Emergency planning; ANP; Uncertainty; Optimization

1. Introduction

Floods, earthquakes and other natural hazards have disrupted human civilization since ancient times, often with devastating consequences [1]. Group decision making is an important characteristic of modern emergency planning and management [2]. For example, in the context of refugee emergency response and contingency planning, the Office of the United Nations High Commissioner on Refugees (UNHCR) [3] promotes the use of "roundtable" meetings in order facilitate group decision making: "The views of one agency may differ from others, but this will often be to the advantage of the planning process since it provides a useful forum for all assumptions to be questioned and refined. The end product is thus more realistic". Civil defense and emergency management group decisions share several unique characteristics. First, the group must often make many complex and multi-faceted decisions in a short period of time, thereby contributing to a high "decision load". Second, these decisions may have potentially serious consequences. Maier [4] uses the term "decision quality" to describe the degree to which a wrong decision could lead to catastrophic results. Third, the group decision must often be made with incomplete information (both in terms of quantity and quality), particularly in the early stages of a disaster because of emergency management problems. Accordingly, the

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development and application of group multi-criteria Decision Support Systems [5–7] could be extremely valuable to support emergency management decisions.

The Group Analytic Hierarchy Process (GAHP) [8–10] and the Group Analytic Network Process (GANP) [11] have great potential for use in group emergency management decision making. For example, Levy [12] describes the use of ANP to improve flood hazard mitigation in the 1998 Yangtze river floods which caused over 3,000 fatalities and affected up to 250 million people. In the ANP, networks with dependence and feedback are constructed, and emergency management judgments are made (or measurements performed) on pairs of elements with respect to a controlling element. An absolute scale (a special instance of a ratio scale with a constant multiplier equal to one, invariant under the identity transformation) of emergency management priorities (values) is derived from sets of pairwise comparisons and ratings. The criteria are pairwise compared with respect to the goal, the sub-criteria with respect to their parent criterion, and the emergency management alternatives with respect to the last level of sub-criteria above them. The emergency management priorities are then synthesized throughout the network to yield the overall priorities for the alternatives.

The remainder of the paper is structured as follows. Section 2 describes current methods for GAHP/GANP under conditions of uncertainty. Advances in mathematical and computer modeling for emergency management GANP are put forth in Section 3. In Section 4, a real world emergency exercise is discussed, involving several emergency management and civil defense groups. In particular, a chemical spill is simulated in the city of Brandon, Manitoba. With application to evacuation and shelter-in-place decisions, it is shown that the proposed GANP technique improves emergency management effectiveness, decision transparency, and user satisfaction. Finally, Section 5 summarizes the main conclusions.

2. Group AHP/ANP under uncertainty

In emergency planning and management decisions, it is often necessary to combine individual preferences to form a group response. To illustrate the "group prioritization" process in the AHP let a_{ij} represent the comparison of element i to element j in a pairwise comparison matrix A for n decision makers. Condon et al. [13] identify four approaches to estimate the weights of elements in GAHP. In the first approach, the emergency management group is required to reach consensus on every entry a_{ij} in the matrix. Saaty and Vargas [14] note that to achieve a decision with which the group is satisfied, it is necessary for the judgments be homogeneous. If consensus is not possible, the second basic approach is to use a vote on the various judgments proposed to pick a compromise for the value of the group entry. A third approach is to aggregate individual preferences into group preferences. For example, if each decision maker generates her own pairwise comparison matrix for each node of the hierarchy (excluding the bottom level nodes), then the same pairwise comparison for each individual is aggregated into a group judgment by taking the weighted geometric mean of all comparisons:

$$a_{ij} = \prod_{k=1}^{n} a_{ij}^{p} \tag{1}$$

where a_{ij} is each person's paired comparison, n is the number of decision makers, and p $(0.0 \leq p \leq 1.0)$ is the importance priority for the person's paired comparison. Aczel and Saaty [15] demonstrate that the geometric mean of the individual judgments is the only averaging process for synthesizing reciprocal judgments that preserves the reciprocal relationship ($a_{ij} = 1/a_{ji}$) in the group pairwise comparison matrix. There are a number of important social choice axioms governing the procedure of group preference aggregation [16] and it has been erroneously claimed, in the context of combining judgments in hierarchies, that the geometric mean violates Pareto Optimality [17]. A fourth group aggregation approach is the weighted arithmetic mean of individual (node or composite) priorities [18, 19]. However, in practice, there are challenges associated with each of these four approaches (consensus, vote or compromise, geometric mean, and weighted arithmetic mean), see for example [20].

Moreover, in emergency management situations, preference judgments are notoriously tentative, imprecise, approximate and uncertain, due to incomplete information or knowledge, the vagueness of the human thinking, and the inherent complexity and uncertainty of the decision environment. A number of group fuzzy prioritization processes for AHP/ANP have been developed to address this problem. The fuzzy-set approach expresses comparison ratios as fuzzy sets or fuzzy numbers, in order to deal with the perceived difficulty in obtaining exact numerical values for