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Evacuation planning using multiobjective evolutionary optimization approach

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ABSTRACT

In an emergency situation, evacuation is conducted in order to displace people from a dangerous place to a safer place, and it usually needs to be done in a hurry. It is necessary to prepare evacuation plans in order to have a good response in an emergency situation. A central challenge in developing an evacuation plan is in determining the distribution of evacuees into the safe areas, that is, deciding where and from which road each evacuee should go. To achieve this aim, several objective functions should be brought into consideration and need to be satisfied simultaneously, though these objective functions may often conflict with each other.

This paper aims to address the use of multiobjective evolutionary algorithms (MOEA) and the geographical information system (GIS) for evacuation planning. The paper proposes a three-step approach for evacuation planning. It explains that the last step, which corresponds to distribution of evacuees into the safe areas, is a spatial multiobjective optimization problem (MOP), because the objective functions and data required for solving the problem has a spatial component. To solve the MOP, two objective functions are defined, different algorithms for solving the problem are investigated, and the proper algorithm is selected. Finally, in the context of a case study project and based on the proposed approach and algorithm, evacuation planning is conducted in a GIS environment, and the results are tested. This paper is based on an ongoing research project in Iran.

1. Introduction

Evacuation is a common strategy for handling emergency situations. Evacuation is a process in which threatened people are displaced from dangerous places to safer places in order to reduce the health and life vulnerability of affected people. During disaster response, evacuation should be conducted accurately, and in a hurry. As a result, preparation, testing and training of a proper evacuation plan are required as a part of disaster preparedness. However, evacuation planning is a very complex problem involving many behavioral and management facets.

There are different studies in evacuation planning that work from different perspectives such as evacuee behaviors, traffic control strategies, sheltering site selection, and route finding for displacement. For example, Sherali et al. (1991) and Kongsomsaksakul and Yang (2005) studied the evacuation plan for hurricanes/floods with explicit consideration of the impact of shelter locations on evacuation time. The former formulated the problem as a nonlinear mixed integer programming problem, but the latter utilized a GA-based solution procedure to solve the problem. Feng and Wen (2003) studied various traffic control strategies for the earthquake-raided area in post earthquake periods and proposed some models to minimize the rescue time in a disaster area. Cova and Justin (2003) presented a network flow model for identifying optimal lane-based evacuation routing plans in a complex road network. A mixed-integer programming solver is used to derive routing plans for sample networks. Murray and Mahmassani (2003) added a consideration of household behavior into evacuation modeling. Yi and Özdamar (2007) proposed a dynamic logistics coordination model for evacuation and support in disaster response activities. Pursals and Garzon (2009) considered the building evacuation problem and developed a model for selecting the proper routs for movement of people in a building during an emergency situation.

Most of the data required for emergency management and evacuation planning have a spatial component or location that represents a significant opportunity to utilize geographical information systems (GIS) (Budic and Pinto, 1999; Mansourian et al., 2006). As a result, GIS-based emergency management and evacuation planning have gained popularity in recent years. Notable examples include Cova and Church (1997), who have presented a method for identifying neighborhoods that may face transportation difficulties during an evacuation. They used an integer programming model called the critical cluster model and demonstrated that a heuristic algorithm is able to produce efficient, high-quality solutions to this

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model in a GIS context. Pal et al. (2003) have discussed the development of a traffic simulation methodology using GIS and spatial data, which could be used for emergency evacuation planning purposes. This methodology seeks to give optimal evacuation alternatives in the form of safest and most efficient routes for evacuation of the population from the affected region. Vakalis et al. (2004) have developed a GIS-based forest fire simulation tool to manage wildfire crises based on a discrete contour propagation model for estimating fire consequences and a fuzzy/neural system for the estimation of fire spread. Zeng et al. (2007) used a heuristic GA method and GIS software in order to manage the risk of wind damage in forest planning. Mansourian et al. (2006) used spatial data infrastructure (SDI) concepts and Web-based GIS to facilitate disaster management. They used Web-based GIS to facilitate spatial data sharing among disaster management parties for better planning and decision-making.

Iannoni et al. (2009) present a method to optimize the configuration and operation of emergency medical systems on highways. This approach is based on embedding a well-known spatially distributed queueing model (hypercube model) into a hybrid Genetic Algorithm (GA) to optimize the decisions involved.

To develop an evacuation plan, it is important to first determine safe areas. Another significant job (and, in fact, a central challenge) involves determining the distribution of evacuees into the safe areas, that is, to answer: where should each evacuee go and from which route (ElDessouki, 1998)? To achieve a proper plan, a planner should consider *the capacities of the safe areas* and *the distance to the safe areas* as two important factors during the planning (Negreiros and Palhano, 2006; Wu and Zhang, 2006). In other words, in an evacuation plan, the distribution of evacuees into the safe areas should be based on the capacity of the safe areas, and, at the same time, each evacuee should go to the nearest safe area. Therefore, in evacuation planning, at least two objective functions should be satisfied simultaneously; the planners are faced with a multiobjective optimization problem (MOP). In addition, since objective functions and the relevant data for their determination has a spatial component (e.g., location of the safe areas, location of the building blocks in which evacuees are, and route map), evacuation planning can be defined as a spatial MOP (this has been also highlighted by Chow and Lui (2002), Georgiadou et al. (2006) and Yi and Kumar (2007)).

Although the potential role of GIS in evacuation planning has been noted by a number of studies, little work has been done in this area (Balram and Dragicevic, 2006). More specifically, there are very few studies integrating GIS and multiobjective techniques for evacuation planning (Balram and Dragicevic, 2006), particularly for the problem of this research With this in mind, this paper intends to address and present utilization of multiobjective optimization techniques and GIS as integrated frameworks for evacuation planning. The paper is based on a case study project in Tehran, the capital of Iran.

2. Methodology and materials

In response to this understanding, this paper proposes a three-step method for an optimized evacuation planning algorithm (Fig. 1). As illustrated in Fig. 1, in the first step appropriate safe places for evacuation are selected/designed. In the second step, by applying some constrains (such as a total distance constraint), appropriate candidate safe areas are chosen for each building block. Then, for each building block, optimum routes to its candidate safe areas are found. In the third step, by considering and optimizing different factors (such as distance from safe areas, the capacity of the safe areas, and the population of the building blocks), an optimum distribution of people to the safe areas is determined.

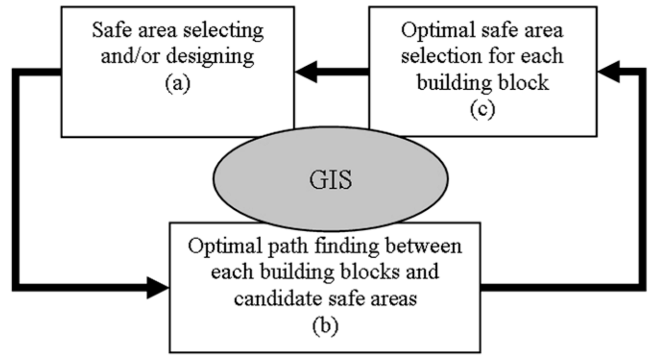

Fig. 1. The proposed evacuation planning procedure.

By following these three steps, *proper safe area* and *the optimum path to get into the safe area* are determined for each building block. The result can then be presented on a map, which is known as an evacuation plan. In order to implement the proposed method, several models, theories, and tools are utilized. These are described as follows.

2.1. Safe area designation

Available vacant lands as well as green and open areas are generally considered as safe areas during an emergency. These areas should have some specifications such as: enough space for evacuees, basic living requirements (water, toilet, electricity, etc.), and not being threatened by any hazard. Through different techniques such as aerial/satellite image processing, field work, and using available maps, appropriate places are identified and then prepared to be usable as a safe area. For the case study of this research, in the context of a comprehensive plan for Tehran disaster management, JICA and TDMMC (2004) had already designed potential evacuation safe areas, so we adopted these areas for our research.

2.2. Optimum path finding

At this step, for each building block, initial candidate safe areas are selected. The selection is based on the nearness of the available safe areas to the building blocks. In this research, in order to find candidate safe areas, three data layers (namely, building blocks, safe areas, and route network of the case study area) were loaded in a geographical information system (GIS). Then, using a buffering tool, a buffer zone was created for each building block. The buffering distance was set based on the experiences of Iranian disaster managers in administrating different disasters such as Manjil (1990), Ghazvin (2002), Bam (2003), and Boroujerd (2006). After this, candidate safe areas for each building block were determined by overlaying the buffer areas with safe areas. In the last stage, optimum paths between each building block and the relevant candidate safe areas were determined using a GIS network analysis tool. The optimum paths were determined by choosing the shortest path satisfying traffic and safety constrains.

2.3. Optimal safe area selection for each building block

The last step of the proposed methodology is to select the proper safe area for the evacuation of each building block. To solve this problem, several factors should be brought into consideration and optimized simultaneously. The two decisive factors are the "distance of building block from assigning safe area" and the "capacity of the safe area". With this in mind, two objective functions, U and V, were defined (Eq. (1)) here. Of these, U models the capacity criterion, while V models the distance criterion.