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An evacuation model coupling with toxic effect for chemical industrial park

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ABSTRACT

Emergency evacuation plan plays a key role for disaster management and successful evacuation. In this work, a conceptual decision support system is established and a method to determine the evacuation scope under toxicant leakage accidents is also proposed. Simultaneously, a route selection approach coupling with polluted scope is proposed based on operation mathematic analysis. The best route for evacuee at each location on toxic leakage accidents is the one along with which the heath injury is minimal. Hence, a variable based on toxic load is defined and noted as $D_{V_i-V_j}$, which is used to quantify the toxic exposure. The universally minimal $D_{V_i-V_j}$ is taken as the optimized goal in the model. And then, one case is presented and indicates that this approach can aid the emergency managers to make the right response to the leakage accident in an efficient manner. This new method is also useful for fire risk assessment and design of chemical industrial park.

1. Introduction

In recent years, chemical industrial park (CIP) is becoming one of the mainstreams of international development and a new developmental mode in the Chinese chemical industry. The CIP can promote the development of the regional economy and chemical industry, and it also brings new safety issues. Toxicant leakage is one of the main types of accidents in CIP. Once happens, it will not only contaminate the environment and disturb the ecosystem, but also bring tremendous injury to the workers or residents around a rather great area. Emergency evacuation is the immediate and rapid movement of people away from the threat or actual occurrence of a hazard, and it is a key factor to lessen the loss. In general, the evacuation system structure, population, behaviors of people at risk, and hazard propagation speed and characteristics will essentially influence the optimal planning for the certain evacuation systems, e.g. buildings, cities or regions. In general, the following lists the information that should be considered in evacuation planning and needs to be estimated if not available (Hamacher and Tjandra, 2002), as shown in Fig. 1:

(1) Type of system defined by layout and familiarity, for example, office building or airport.
(2) Behavior estimation of the occupants under panic situation.
(3) Occupants' distribution, including age, gender and disability.
(4) Source and location of hazard, hazard propagation speed and factors affecting the hazard propagation.
(5) Safe destinations.
(6) Availability of emergency service facilities and personnel.

In the mathematic research area, many models and algorithms that can be applied to simulate evacuation processes have been proposed and they can be generally classified into macroscopic models and microscopic models. The macroscopic models ignore the individuals' behaviors during emergency situations and are mainly based on network flow models including statics network (Chen and Chin, 1990; Yamada, 1996), discrete time dynamic network (Chalmet et al., 1982; Fleischer, 2001a; Kostreva and Wiecek, 1993; Wilkinson, 1971), continuous time dynamic network (Anderson et al., 1982; Fleischer, 2001b) and traffic assignment (Janson, 1991; Sheffi et al., 1982). Microscopic models consider the individuals' characteristics and interactions in evacuation processes. Since huge amount of data are required in the microscopic simulations, recently there is a growing interest in the impact analysis of human factors on pedestrian traffic

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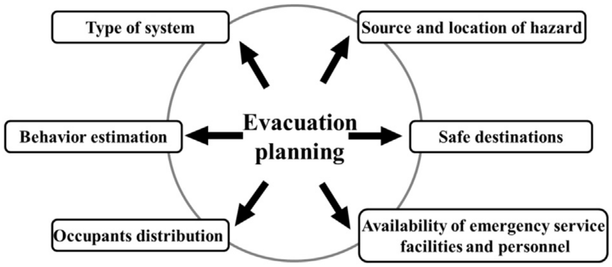

Fig. 1. The structure of an ideal evacuation planning.

characteristics (Ma et al., 2012; Peacock et al., 2012; Spearpoint and MacLennan, 2012), such as velocity, age, personal feature of prior knowledge of the surroundings and so on. Hence, various probabilistic models and cellular automata have been proposed to simulate the pedestrians' movements (Blue and Adler, 2002; Chen et al., 2012; Chooramun et al., 2012; Meyer-Konig et al., 2002; Xu and Song, 2009; Zhao et al., 2006; Zheng et al., 2011). Besides, a series of evacuation planning approaches based on the above methods in disaster response activities have been generated. For the moving hazardous materials, Bonvicini and Spadoni proposed an OPTIPATH model to solve the routing problem and integrated into the TRAT4-GIS software for transportation risk analysis (Bonvicini and Spadoni, 2008; Leonelli et al., 2000). However, few models have been reported on the optimization evacuation routes in case of toxicant leakage accidents which have catastrophic impacts on the local population and environment. Therefore, great efforts should be put on in finding an approach to optimize the routing progress when encounter with the toxicant leakage accidents. Additionally, from 1990s', many polluting industries have been transferred from the developed countries to the developing countries. Hence, Chinese researchers have made great efforts in researching the toxicant leakage accidents. Admittedly, the definition of "Equivalent Length" proposed by Wen and Chen (1999) is great progress in finding the best route in case of toxicant leakage accidents. Nevertheless, just giving a "Dangerous Parameter" to each dangerous zone according to affected severities is not enough to make a successful evacuation plan.

In this work, a conceptual decision support system for toxic leakage was established and a method of determining the protective action distances (PAD) and protection action zones (PAZ) also was proposed. Based on the mathematical analysis of operation research method, an evacuation model considering the special characteristics of leakage accidents was reported with the universally minimum injury as the optimized goal. Furthermore, this model was proved to be more accuracy and applicable by comparing with current models. Finally, a case study was presented and a Gaussian plume model was adopted to make the model more understandable.

2. Conceptual model of emergency decision system for toxicant leakage accident

Huge amounts of toxicant and dangerous chemicals are stored in CIP. Once leakage, it will lead to great disasters with many people seriously injured. In order to make a successful decision, the following five issues must be addressed:

- Which areas will be affected?
- What is the magnitude of the consequence of leakage?
- How to measure the damage of leakage gas to evacuees?
- Have shelter places been decided in advance?
- Which are the best routes for evacuees at different locations?

In this section, a conceptual emergency decision system of toxicant leakage accidents was established using a five-step procedure and the objective goal of the decision system is to find the best route along with which the injury to evacuees at each location is minimal. The first step of the decision system is to identify risk areas. This is accomplished by collecting the leakage data and the weather conditions when accident occurs. The second step is to build the evacuation network and the information about the distribution of evacuees should be achieved in advance. Besides, the geographic information of the chemical park is also important for the accomplishment of the above two steps. Then, the total damage of leakage gas to individuals' health can be calculated based on the success of the above processes. In this paper, a variable (noted as $D_{V_i-V_j}$) based on toxic load was defined to quantify the adverse health consequences to evacuees. Additionally, a mathematical gas leakage model was employed. The fourth step is divided the system into two cases and emergency managers should make the reasonable decision according the different situations. Finally, a successful evacuation planning can be made, as shown in Fig. 2.

3. Determination of evacuation scope

In a successful decision system for CIP, the value of mathematic methods is particularly high when considering toxic-by-inhalation (TIH) chemicals. These are chemicals that easily produce toxic atmospheric concentrations that can extend for miles downwind of the accident site and the concentrations of chemicals decrease with distance from the release point. Therefore, it is important to determine the range of consequences that can occur for a given release amount. The United States Department of Transportation (DOT) incorporated with Transport Canada and Secretariat of Transport and Communications of Mexico publishes the Emergency Response Guidebook (ERG) (Transportation, 2012). A key section of this book lists protective action distances for leakage accidents. These distances are defined and illustrated in Fig. 3(a). The protective active zones are square regions having a side dimension

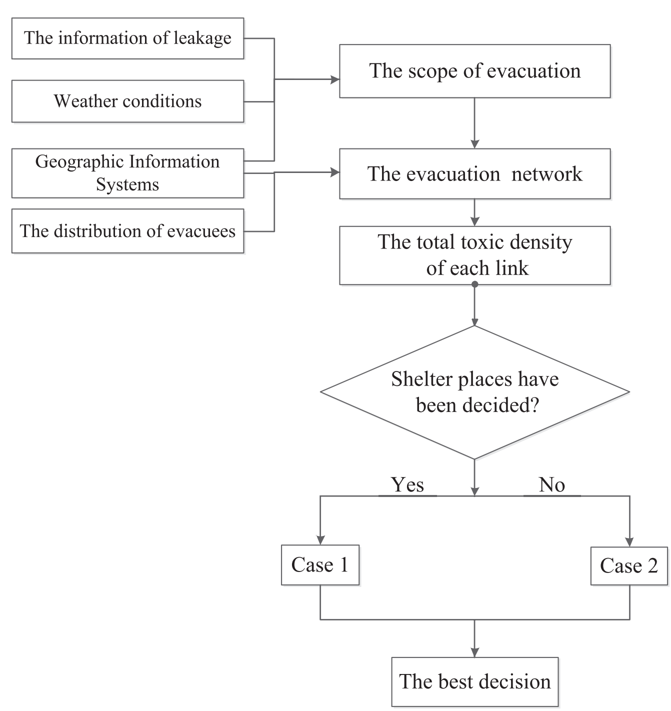

Fig. 2. A framework of decision support system process diagram.