JOURNAL OF TRANSPORTATION SYSTEMS ENGINEERING AND INFORMATION TECHNOLOGY
Volume 12, Issue 4, August 2012
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this article as: J Transpn Sys Eng & IT, 2012, 12(4), 143−148.

RESEARCH PAPER

Traffic Evacuation of Cellular Network after Dangerous Goods Spill

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Abstract: After dangerous goods spilling, the emergency evacuation transportation of the hazardous area is rather important to reduce personal injuries and economic losses. This paper analyzes the emergency evacuation on major and core road networks during a given time. The objective function is a cell model for regional emergency evacuation considering road network capacity. Then, combining with the complexity of the model characteristics and advantages, the quantum particle swarm model is solved. The example shows that under emergency situations, if the traffic management department makes most of the information superiority and dominant road network evacuation capacity, the evacuation capability will increase by 56.9% than normal cases. The proposed models and algorithms provide a theoretical support for emergency traffic management.

Key Words: integrated transportation; emergency evacuation; cell model; dangerous goods; quantum particle swarm optimization; maximum evacuation traffic

1 Introduction

At 8:45 pm on July 23rd, 2011, a tank truck loaded with a high concentration of hydrochloric acid rolled over as it was traveling 1726 km in the city direction of the Shanghai–Chongqing freeway. The tanker crossed the central isolation belt, suppressed a reverse driving car, and caused a chain collision of three vehicles behind and traffic interruption for almost 4 hours. After the accident, totally 7.5 tons of hydrochloric acid in the tank leaked off, and the pungent odor and smoke forced the passing drivers to abandon their vehicle and evacuate rapidly. At that moment, thousands of people escaped emergently from the Shanghai–Chongqing freeway. As is known to all, emergency evacuation is the main function module in emergency management. Many scholars at both home and abroad have focused on the emergency evacuation. Chen and Shuai[1] improved the emergency evacuation model by analyzing the dynamic and time-varying characteristics of the emergency evacuation with the dangerous goods leak. A dynamic road network vehicle emergency evacuation model is proposed by employing the dynamic traffic assignment theory, in which a total vehicle minimum evacuation time is assumed as the objective function, and the particle swarm optimization algorithm is applied to derive the solution. Li et al.[2] introduced accident risk factors and evacuation directions in the risk evaluation model of the city emergency traffic evacuation by considering the hazards, in which the negative correlation between the accident risk factors and the distance is considered fundamental toward expressing the influence of hazards on emergency evacuation traffic. Yang[3] presented a simulation training system of the dangerous chemical accidents evacuation, which included the database, the model base, and the knowledge base. Zhang *et al*.[4] designed an evacuation decision-making system for hazardous chemical accidents based on ArcGIS in view of the frequent occurrence of the hazardous chemical accidents. Wang *et al*.[5] studied the emergency vehicle evacuation under the emergency situation and proposed a model that evaluates the evacuation capacity of the network. Cui[6] studied the emergency management in consideration of the emergency evacuation traffic management globally; provided suggestions on both emergency transport modeling and the emergency traffic evacuation; however, their study was not quantified. With regard to the city evacuation, Cui *et al*.[7] optimized the public transportation system by assuming the shortest total evacuation time to be the objective based on the bus system.

Received date: Feb 20, 2012; Revised date: Mar 23, 2012; Accepted date: Apr 5, 2012
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DOI: 10.1016/S1570-6672(11)60219-5

Liu and Hu[8] reviewed several literatures on the emergency transportation evacuation and drew the conclusions that the bus should be given priority in the emergency transportation evacuation of China. Chen and Xiao[9] explored the dynamic emergency traffic evacuation and adopted the Pontryagin method to solve the model. Wu *et al*.[10] simulated the city traffic emergency evacuation. Yamada[11] optimized the emergency traffic evacuation from the viewpoints of minimum cost and minimum distance. Cova and Johnson[12] put forward an emergency traffic lane evacuation model that studies the emergency transportation evacuation in a complex network. Yang[13] introduced the shortest path optimization model for the special vehicles used in the emergency transportation evacuation, such as police vehicles, fire engines, and so on. Many scholars studied the emergency transportation evacuation problem from various perspectives, but very few of them took consideration of the influence of the emergency traffic management agencies on the evacuation, even though they play very important roles in emergency transportation evacuation. When the leakage of the dangerous goods possessing a diffusivity occurs, massive vehicles will evacuate from the dangerous area undergoing this situation, the emergency evacuation road network becomes rather vulnerable due to the information asymmetry of people to the evacuation road network and the time-varying characteristic of the emergency evacuation road network; and the transportation vulnerability of some regions or points in the road network will be displayed as well. The Emergency Traffic Management Agencies can use their information advantage as well as administrative powers to carry out an effective evacuation for the vehicles in the emergency evacuation road network. In this article, the emergency evacuation road network is optimized by employing the cell transmission model for the dangerous goods possessing a strong diffusivity when a large-scale diffusion happens, and the quantum particle swarm algorithm is adopted to solve the model.

2 Description of the problem

After a large-scale diffusion of the dangerous goods possessing a strong diffusivity, the vehicle evacuation in the road network becomes very important. The emergency evacuation in the road network has the characteristics of variability, dynamics, and blindness in reality. People are very nervous, and the road network has huge uncertainty with regard to the emergency evacuation road network, which will make it difficult for people to acquire complete and accurate information on this network. In this situation, the public may take a group decision which may cause some sections of the emergency evacuation road network to become very crowded, and the traffic network evacuation capacity becomes very fragile and unstable. Therefore, it is necessary that the emergency traffic management agency leads the emergency rescue vehicles and other vehicles to evacuate orderly in the damaged area by using the comprehensive information of the emergency evacuation road network obtained from their information systems. The objective of this article is to evacuate as many vehicles as possible within a limited time. The cell transmission model (CTM) is employed to describe the evacuation of the emergency transport road network in this article. Compared with the model in Ref. [1], the cellular model proposed in this article possesses the follow advantages: (1) The cell transmission model discretizes the vehicle flow into many single vehicles to overcome the shortcomings of the low computation efficiency of the large-scale network; can capture the discontinuous change phenomenon in the traffic network and distinctly describe the physical effect of queuing; and can simulate the traffic dynamic characteristics of the shock wave, queue formation, queue dissipation, and the interaction between multiple sections. Therefore, the CTM has been used in dynamic traffic assignment for both enhancing the accuracy of the estimation of the path impedance and improving the efficiency of dynamic traffic assignment. (2) Compared with the other emergency traffic evacuation models, the proposed model introduces the emergency traffic management into the emergency transport road network evacuation, which enables the static network to become a dynamic road network that better fits the actual situation (In some cities of China, the two-way lane becomes a single-way lane that diverges the traffic flow in some time period).

The model is as follows:

In the cell transmission model, each road section on the emergency evacuation network is divided into multiple equidistant subsections (cellular); the emergency evacuation time is discretized, and the length of the cell equals the evacuation distance covered in a time step of the emergency evacuation. The model parameters are defined as follows:

T: the time segment assembly of the emergency evacuation road network;

C: all the cellulars in the emergency evacuation network; C_G: the common cellular in the emergency evacuation road network; C_R: the source cell assembly in the emergency evacuation road network; C_S: the ending cellular in the emergency evacuation road network; C_D: the diverging cellular in the emergency evacuation road network; C_M: all the converging cellulars in the emergency evacuation road network;

E: all the connective cellulars in the emergency evacuation road network system; E_G: all the connective common cellulars in the emergency evacuation road network system; E_R: all the connective source cellulars in the emergency evacuation road network system; E_S: all the connective ending cellulars in the emergency evacuation road network system;

$\Gamma^{+1}(i)$: all the inherited cellulars of cellular i in the