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A real-time stochastic evacuation model for road tunnels

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ABSTRACT

Traditionally most of egress models have been mainly used for performance-base assessment and forensic analyses. But their use has been extended to other applications such as real-time mode. In this paper we present EvacTunnel® a real-time model integrated in a Decision Support System (DSS) for emergency management in road tunnel. The proposed model is based on the idea that, in some scenarios such as road tunnels, egress calculations can be performed by addressing a small set of random parameters that have a great impact on outcomes. These parameters are identified as pre-movement times (recognition and response time), travel distances and unimpeded walking speeds. Based on Monte Carlo methods, the model has the capability to perform multiple simulations by changing random variables. As a first stage of verification process, the proposed model is compared with other validated evacuation models. The results are essentially coincident in all models. Based on this analysis it can be argued that the model provides consistent and reasonable results. But the main difference is that the proposed model can provide results faster than real-time (less than 5 s) while the run time of the other models is really higher.

1. Introduction

Recent history has shown that tunnels constitute dangerous environments in case of emergency. Over the past few decades, seven important accidents in tunnels (1987–2008) have caused over 400 deaths (Carvel and Marlin, 2004). Disasters such as the Mont Blanc Tunnel fire (Italy–France, 1999) and the St. Gotthard Tunnel fire (Swiss Alps, 2001) have shown the need for an effective emergency response. The tunnel safety is dependent on three main factors: (1) tunnel design, (2) tunnel management and (3) emergency response (Burns, 2004). However, current road tunnel safety is limited by the traditional approach focused on the tunnel design and facilities, risk analysis and contingency plans. Prevention is a key factor but it does not solve the problem once the accident has occurred. Given an incident or accident inside a road tunnel, the operator is the first person to handle the situation. Therefore he/she is a key figure in communication with occupants with his/her supervisor and the emergency services (Tesson, 2009). But, during the first stages of the incident or accident, the information may be sparse, incomplete and inaccurate and the tunnel operator will be required to make right decisions.

In this context, the GIDAI Group at University of Cantabria has carried out a research project – funded by the Spanish Ministry of Transport – that aimed to develop a Decision Support System (DSS) for emergency management in road tunnels. The DSS is intended to improve the emergency management in road tunnels. It is integrated by the following models: (1) incidents model, (2) evacuation model (EvacTunnel®) and (3) decision model. The system provides the operator the course of actions to deal with the emergency, such as close the tunnel, active the emergency services, declare the evacuation, and maximum levels of illumination (Capote et al., 2010, 2011). Furthermore, the system provides to the operator a real-time estimation about (1) the severity of the accident (number of fatalities, number of injured people) and (2) the total evacuation time (self-rescue and rescue processes).

It is well known that egress models have been used as a tool for analyzing occupants' safety conditions in case of emergency. These models have been mainly used for performance-base assessment and forensic analyses. But their use has been extended to other scenarios and applications such as real-time mode (Gwynne and Kuligowski, 2008; Capote et al., 2012; Wenxuan Ding, 2011). The real-time mode allows the operator to acquire feedback from the model during an actual situation. This requires a direct observation from the real situation (i.e. through CCTV) and then provides this information directly to the egress model which should provide a run time significantly faster than real-time (Gwynne and Kuligowski, 2008) to obtain results even before the evacuation process has begun. However, most current egress models are getting more and more sophisticated. But these models have two problems for real-time applications: (1) they run slower than real-time and (2) their sophistication may obscure the key aspects and the accuracy in which they are treated (Purser and Gwynne, 2007).

Some evacuation models can run in real-time mode (Kisko and Francis, 1985; Bukowski et al., 2002; Yamashita et al., 2011). These models are mainly developed for buildings. The real-time

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evacuation models are likely to be less sophisticated and therefore produce limited information due to time constraints (Gandit et al., 2008). This is especially important in complex environments (multi-enclosure buildings) where occupants have various options or ways to evacuate. The proposed model is based on the idea that, in some scenarios such as road tunnels, egress calculations can be performed by addressing a small set of random parameters that have a great impact on outcomes. These parameters are identified as), pre-movement times (recognition and response time), travel distances and unimpeded walking speeds.

The challenge was to obtain equilibrium between run times (faster than real-time) and the efficiency of the model to provide accurate results. It is well known that occupants' actions and decisions can have a great impact in evacuation process (i.e. people may remain passive inside their vehicles) (Proulx, 2002; Centre d'Ëtudes des Tunnels, 2003). These actions and decisions are unknown prior to an event. To address this, Monte Carlo methods can be used varying the random parameters in order to capture all the possible situations in which the road tunnel might be evacuated. The real-time applications require processing the output information quickly enough and analytical tools are needed to assist the model user (the tunnel operator) in this process. Therefore, the information provided need to be easy to interpret. For instance, given a scenario, the main output parameter may be the percentile (90, 95 and 99th) of total evacuation time. In this paper we present a real-time evacuation model for road tunnels which operates in the manner described above.

2. The Decision Support System (DSS)

Fig. 1 shows the Decision Support System (DSS) schema. When an incident or accident occurs, the tunnel operator detects the emergency through the Automatic Incident Detection (AID) and/or CCTV or by other ways such as SOS or fire detection systems in case of fire. Then the tunnel operator set up input variables in the Incidents Model. Table 1 shows the Boolean and Numerical input variables.

Outputs from Incidents Model are used as inputs for the Evacuation and Decision Models. These outputs are divided into two parts: (1) possible decisions to deal the emergency for the Decision Model and (2) estimations about the occupants (people with normal, reduced and assisted mobility) and the evacuation distances for the evacuation model. The Decision Model processes the information and displays the actions such as close the tunnel, active the emergency services, and order evacuation. If the evacuation is required, then the model simulates the process and predicts the Required Safe Egress Time (RSET).

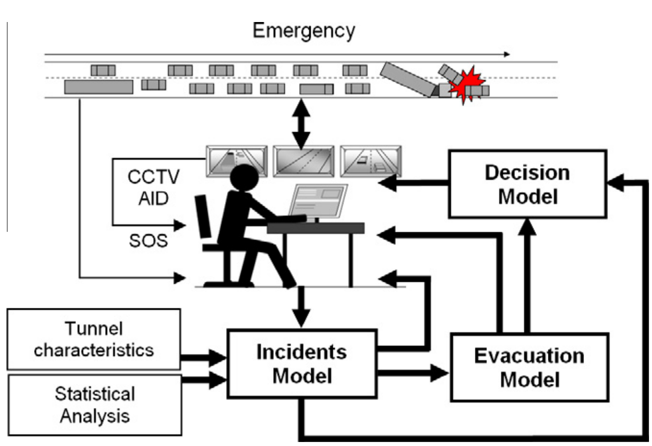

Fig. 1. Decision Support System (DSS) for emergency management in road tunnels.

Table 1
Inputs used in the Incidents Model.

Boolean variables	Numerical variables	
Is there an accident?	Number of lanes blocked	N° of cars involved
Is there a fire?	N° of surveillance-camera	N° of vehicles trapped
Is there a spillage?	N° of vehicles involved	Detection time
Is there any injured person?	N° of heavy vehicles involved	
Is there a serious incident?	N° of buses involved	

3. EvacTunnel overview

This is an object-oriented evacuation model, programmed in Microsoft Visual C# 2008. The model is integrated in the DSS for emergency management in road tunnels and it can run on any PC. The set up is easy and the model can perform multiple simulations in real-time. As Fig. 2 shows, the model considers two areas: Area 1 and Area 2. The Area 1 includes the vehicles and the people directly involved in the accident. The Area 2 includes the vehicles and people trapped inside the tunnel not directly affected by the accident. Each area is a node where each occupant is taken into account and his/her behaviour is represented by the following random parameters (pre-movement time and walking speed). Furthermore, the initial location of each occupant and their travel distances are considered as a random variable too. At the moment the current version of the model does not include smoke and toxic influences on evacuation process.

The presented model allows performing several simulations within a few seconds obtaining a sample of total evacuation times. The model statistically treats the sample of total evacuation times and fit it to a known distribution (if possible). Otherwise, density estimation is given using histogram. The main output parameter is a percentile of evacuation times (0.90, 0.95 and 0.99). The model also provides other statistical characteristics: mean, variance, maximum and minimum values. It should be noted that each of these areas (Area 1 and Area 2) are different scenarios with different characteristics. In the Area 1 it is likely to find injured people who cannot evacuate by themselves (rescue process), people from Area 2 can leave the tunnel by foot (self-evacuation process). For this reason the proposed model calculates both scenarios separately. In fact, we can talk about two different evacuation models: evacuation model of Area 1 and evacuation model of Area 2.

3.1. Evacuation model of Area 1

The basic inputs for the evacuation model of Area 1 obtained from Incidents Model are following:

- $a'_{BIDIREC}$ – True when people can evacuate in both directions from the accident.
- d'_{I1} – Distance from the portal to the beginning of Area 1.
- d'_{I2} – Distance from the exit (portal or cross passage) to the end of Area 1.
- n'_{IT} – Estimated number of occupants in the Area 1.
- Estimated number of occupants with:
- n'_{INM} – Normal mobility – Number of people none affected by the accident.
- n'_{IRM} – Reduced mobility – Number of people affected by the accident who can evacuate by themselves.
- n'_{IAM} – Assisted mobility – Number of people affected by the accident who cannot evacuate by themselves and need to be rescued.