Infrequent Events Model for Road Tunnels

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ABSTRACT

In order to allow proper management of emergencies in road tunnels, a project is currently being developed by the GIDAI Group of University of Cantabria, funded by the Spanish Ministry of Transport. The main purpose of this project is to develop a Decision Support System for the management of emergencies in road tunnels. This system consists of three basic models: an Infrequent Events Model, an Egress and Intervention Model and a Decision Making Model. In this paper, only the Infrequent Events Model is described. This model is developed primarily using methods such as Black Box, Boolean Algebra and Probability Theory. Mathematical equations related to the output and input variables as well as the corresponding computational model are described in detail.

KEYWORDS: Infrequent Event, Road Tunnel, Model

INTRODUCTION

Infrequent events in road tunnels (fires, accidents etc.) are varied and often unpredictable, thus it can be difficult to make the right decisions [1]. The quality of the decisions made depends on the quality of available information. The tunnel operator, who is responsible for monitoring and controlling the road tunnel [2], may have limited information about the incident [3], and may also be under high stress [4]. Currently, the tunnel operator must follow general prescriptive guidelines on how to proceed – few systems exist to support their decisions based on the variables of this specific situation. Computational models can thus be used in order to provide more information and support decisions, helping to provide a more accurate and efficient response. In this paper, an Infrequent Events Model for road tunnels is described. This model will be integrated into a Decision Support System. First, the input variables concerning the scenario and it´s environment are defined. The inputs of the Egress Model are established, and the characteristics of the environment are also defined. Next, the mathematical methods that adequately represent the scenario and environment are defined. Finally, the computational model is described. Importantly, the model has a simple user interface and the outputs are obtained in real time. The results can be divided into two parts. The first part relates to decision making recommendations, such as whether to close the tunnel or to order the evacuation, and the second part relates to the statistical information estimated about the accident.

VARIABLES

A road tunnel can be divided into two different zones:

Zone I - the area directly affected by the accident. This area includes the vehicles and the people directly involved, the area in which vehicles and people are in danger due to fire or hazardous spillages and the emergency exits near the accident.

Zone II - the area adjacent to Zone I. When the tunnel is closed a bottleneck is formed. The people trapped inside the tunnel (in their vehicles) who are not directly affected by the accident have to be evacuated for their safety. The cars trapped inside the tunnel can obstruct evacuation, however, the space is wider in Zone II than in Zone I, and thus it is easier for people to evacuate here.

Inputs – these depend on the information detected in the tunnel control centre. These variables can be divided into two parts: the Boolean variables and the Numerical variables.

Boolean variables	Numerical variables	
Is there an Infrequent Event?	Number of lanes blocked	Number of buses involved
Is there a fire?	Surveillance-camera number	Number of vehicles trapped
Is there a spillage?	Location of the incident	Detection time
Is there an injured person?	Number of vehicles involved	
Is there a serious incident?	Number of heavy vehicles involved	

Table 1 Inputs used in the Model.

Outputs – these are used as inputs into the Egress and Intervention Model. Two types of outputs can be considered: the possible decisions to make and the numerical results obtained by statistical analysis of the available data from accidents in road tunnels

Possible decisions	Numerical results	
Inform the Tunnel Staff	Number of lanes to close	Number of people with reduced mobility
Inform the Emergency team	Distance to the beginning of Zone I	Number of people with assisted mobility
Deploy the Emergency Services	Distance to the end of Zone I	Distance to the end of Zone II
Evacuate the tunnel	Number of people	Number of vehicles trapped in Zone II
Choice of two exits in Zone I	Number of people with normal mobility	Detection time

Table 2 Outputs used in the mathematical model.

MATHEMATICAL MODEL

Parameter	Description
m_{CAR} / m_{MAX}	Number of lanes closed/Number of lanes in the tunnel
α'_{APE}	Inform Tunnel Staff
α_{SI}	Infrequent Event is detected
$\alpha'_{PSE} / \alpha'_{ASE}$	Inform/Deploy Emergency Services
$\alpha_{FIRE} / \alpha_{VSP} / n_{HER}$	Fire/Hazardous spillage /Number of injured people detected
$\alpha'_{EVAC} / \alpha'_{BIDIREC}$	Evacuation is ordered /True when people can evacuate in both directions
d_{GAL_j}	Distance from the entrance to the j^{th} Emergency Exit
A_G	A serious event is detected
d_{SI}	Distance from the entrance to the Infrequent Event
L_T	Tunnel length
Δ_{CAM}	Distance between surveillance cameras
K_{VL}, K_{VP}, K_{VA}	Car, heavy vehicle or bus occupancy
$n_{VLDI}, n_{VPDI}, n_{VADI}$	Number of cars/heavy vehicles/buses directly involved in the accident
$n'_{IMN}, n'_{IMR}, n'_{IMA}$	Number of people evacuating with normal/reduced/assisted mobility
$P(MN(MR, MA) \mid A_{GSI})$	Probability of people with normal mobility (reduced or assisted)
$d_{CAM}(n_{CCTV})$	Distance from the entrance to the surveillance camera that has detected the accident

Table 3 Parameters used in the mathematical model.

The mathematical model consists of a set of expressions which relate the inputs and outputs:

1. Number of lanes closed is equal to the number of lanes blocked due to the Infrequent Event.

$$m'_{CAR} = m_{CAR} \tag{1}$$

2. If an Infrequent Event is detected, tunnel staff are informed.

$$a'_{APE} = a_{SI} \tag{2}$$

3. If one or more lanes are closed, the emergency services are informed.

$$a'_{PSE} = (m_{CAR} \geq 1)^\wedge(m_{MAX} > 1) \tag{3}$$

4. If a fire or hazardous spillage is detected, or the operator suspects that there is an injured person, the emergency services are deployed.

$$a'_{ASE} = (m_{CAR} = m_{MAX}) \vee (a_{FIRE}) \vee (a_{VSP}) \vee (n_{HER} \neq 0) \tag{4}$$

5. If a fire or hazardous spillage is detected, the tunnel should be evacuated immediately.

$$a'_{EVAC} = (a_{FIRE}) \vee (a_{VSP}) \tag{5}$$

6. If the Road Tunnel is completely closed, bidirectional exiting is not possible.

$$a'_{BIDIREC} = m_{CAR} < m_{MAX} \tag{6}$$

7. Distance from the entrance to the beginning of Zone I (d'_{I1}).

$$d'_{I1} = \begin{cases} d_{GAL_i} \ si \ A_G = (i \geq 1)^\wedge \left[\left(d_{SI} - d_{GAL_i}\right) < \left(d_{SI} - d_{GAL_j}\right) \right]^\wedge (j < i) \\ 0 \ \ si \ \overline{A_G} \end{cases} \tag{7}$$

8. Distance from the entrance to the end of Zone I (d'_{I2}).

$$d'_{I2} = \begin{cases} (d_{GAL_k} \ \ si) A_{G1}{}^\wedge a'_{BIDIREC} \\ L_T \ \ si \ \overline{A_{G1}}{}^\wedge a'_{BIDIREC} \\ d_{SI} + \frac{\Delta CAM}{3} \ \ si \ a'_{BIDIREC} = false \end{cases} \tag{8}$$

9. The number of people to evacuate from Zone I (n'_{IT}) depends upon the type and number of vehicles directly involved in the accident. The model assumes maximum evacuation times (worst case scenario).

$$n'_{IT} = K_{VL} \cdot n_{VLDI} + K_{VP} \cdot n_{VPDI} + K_{VA} \cdot n_{VADI} \tag{9}$$

10. A worst case scenario is used to predict the number of people with different mobilities.

$$\left. \begin{aligned} n'_{IMN} &= P(MN|A_{GSI}) \cdot n'_{IT} \\ n'_{IMR} &= P(MR|A_{GSI}) \cdot n'_{IT} \\ n'_{IMA} &= P(MA|A_{GSI}) \cdot n'_{IT} \end{aligned} \right\} \tag{10}$$

11. Distance from the entrance to the end of Zone II (d'_{II}) is equal to the distance to the surveillance camera which has detected the Infrequent Event.

$$d'_{II} = \begin{cases} d_{CAM}(n_{CCTV}) & si\ d'_{I1} \neq 0 \\ 0 & si\ d'_{I1} = 0 \end{cases} \quad (11)$$

12. The number of people to be evacuated from Zone II (n'_{IIV}) is equal to the number of vehicles trapped inside the tunnel (n_{VAT}) minus the number of vehicles directly involved in the accident (n_{VDI}).

COMPUTATIONAL MODEL

The computational model is based upon the mathematical model previously described, employing the Object Orientated Programming Language C# on the. NET Framework 3.5 SP1 using Microsoft Visual Studio 2008. The model is comprised of two main classes: public class *ParamsSI* and *ModSI*

ParamsSI is defined in the file named *SucesoInfrecuente.cs,* which contains the tunnel parameters and has an overloaded constructor that accepts a string variable as a parameter. This constructor opens a **. ds1* file containing all the values of the parameters required by the model. It also assigns these values to the variables of the object class created. If a Boolean variable does not exist in the file, a true value is assumed. Class *ModSI* contains inputs and outputs determined in the mathematical model and an overloaded constructor (string variable) using the tunnel parameters from class *ParamsSI*. This class has a main method named *Procesamiento*, where the equations of the mathematical model are implemented.

The model was validated by creating two programs: *ParametrosSI_1.exe* and *ModeloSI.exe*. *ParametrosSI_1.exe* introduces, solves or changes the characteristic parameters of the tunnel though a **.ds1* file. The program *ModeloSI.exe* checks the computational model, verifying if the outputs correspond with the results of the mathematical model. In this program, the parameters of the tunnel (**.ds1* file*)* should be selected by the tunnel operator. Previously defined inputs corresponding to the Boolean and Numerical variables (see Table 1) should then be introduced into the *ModeloSI.exe* program. Finally, the outputs are obtained using the different inputs and the mathematical model.

CONCLUSIONS

The developed model allows adequate simulation of Infrequent Events in road tunnels. The model is designed for integration into an Automated Decision Support System for Safety in Road Tunnels. The importance of easy integration of this model in this type of computerised system was considered.

This model has primarily been developed using methods like Black Box and others from Boolean Algebra and Probability Theory. The inputs, outputs and other parameters have been defined, as well as the mathematical relationship between them.

This is part of the first phase of a project whose end result will be a complete tool to aid decision making for the tunnel operators in emergency situations. The next steps include the development of an Egress and Intervention Model and the final Decision Making Model.

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