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A model of the decision-making process during pre-evacuation

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ABSTRACT

The behaviour of building occupants before the purposive movement towards an exit, known as the pre-evacuation behaviour, can have a strong impact on the total time required to leave a building in case of fire emergency as well as on the number of casualties and deaths. The pre-evacuation time can be simulated within computational models using different approaches. This work introduces a new model for the simulation of pre-evacuation behaviour based on the Random Utility Theory. The proposed model represents the pre-evacuation behaviour of simulated occupants considering three behavioural states: normal, investigating and evacuating. The model simulates the probability of choosing to start investigating and evacuating in relation to physical and social environmental factors as well as personal occupant characteristics. These two decisions make occupants pass from their starting normal states to investigating and evacuating states. The paper presents a case study of the proposed pre-evacuation time model using an experimental evacuation data set in a cinema theatre. The application of the model allows identifying the main factors affecting the decision to move from a state to another. In the present case study, the main factors influencing the decisions were the time elapsed since the start of the alarm, the occupant's position, and social influence. The issues associated with the implementation of the model are discussed.

1. Introduction

The performance-based design approach requires evaluating the safety of buildings by comparing the time available for occupants to evacuate and the time required to reach a safe place [1,2]. The former time is known as Available Safe Egress Time (ASET) whereas the latter as Require Safe Egress Time (RSET). In Fire Safety Engineering as well as in Crowd Safety, RSET depends upon human behaviour and can be estimated by using computational tools [3,4]. Most of these tools simulate occupant's evacuation using two times, namely, the pre-evacuation time and the movement time, according to the paradigm of the time-line model [3,5,6]. The pre-evacuation time starts when occupants are exposed to the first cues, e.g. alarm, smoke, etc., and ends when they begin to evacuate moving towards a safe place. The movement time is the time spent by the occupants to reach a safe place once they start their purposive movement towards it. Different classifications have been developed to categorize the times characterizing pre-evacuation time. The most common sub-division includes recognition and response time [1,2,5,6]. The recognition time is the time required for an occupant to take the decision to evacuate. During this time, an occupant can either continue with his/her pre-emergency activities (i.e. the action s/he is doing before the emergency starts) or begins to investigate seeking for further information. The response time is the interval between the time at which the evacuation decision is taken and the time at which an occupant starts moving towards a safe place. Different actions can be performed during this time and evacuation could not be the first one [7]. Therefore, the response time involves a complex decision-making process. Occupant can plan all the protective actions to take before starting moving towards a safe place [7].

Many studies have shown that the pre-evacuation time can be an important component of the RSET [6,8,9]. Moreover, the analysis of real emergencies have shown that there can be a correlation between pre-evacuation time and the number of deaths or injuries [8]. To date, full-scale evacuation experiments and real emergencies have been used to quantify the pre-evacuation time for different building types such as residential, commercial, cinema, etc. [10,11]. Other studies have been made to investigate factors characterizing the social/physical environment (i.e. external factors) and factors characterizing the occupant (i.e. internal factors) that could influence pre-evacuation behaviour [7,12,13]. However, pre-evacuation behaviours are generally less documented and quantified than movement behaviours [5,8].

To date, different theories and models have been proposed to

Abbreviations: ASET, Available Safe Egress Time; ES, Evacuating State; IS, Investigating State; NS, Normal State; RSET, Require Safe Egress Time; RUT, Random Utility Theory

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explain the decision-making process characterizing the choices made during pre-evacuation time [7,14,15]. Further quantitative analysis has been done to test some of these conceptual models by using statistical analysis (i.e. multiple regression analysis) [12,13]. Despite the above mentioned theories on evacuation behaviour, most of existing engineering evacuation models still adopt simplistic assumptions and simplifications about occupant behaviour during pre-evacuation [15,16].

At a conceptual level, three main modelling approaches have been proposed to represent the pre-evacuation time [15]. The first approach relies on the deterministic user assignment of a pre-defined time to individuals or groups or a pseudo-random number obtained from a distribution. The simulated occupants (i.e. agents) remain stationary in their initial position until the assigned pre-evacuation time is over. The second approach involves the user assignment of sequences of pre-evacuation actions. The simulated occupants move to different parts of the simulated building to perform their activities. Each action has a pre-defined specific duration for each occupant. The main weakness of these first two approaches is that the behaviour is not actually predicted by the models but they are based on user assumptions [15]. This limitation has been overcome using the last approach, which is instead a predictive-based approach. In this last case, agents perform protective actions in accordance with different factors. Kuligowski [15] states that the main limitation of this approach is the 'homogeneity' assumption which says "*occupants react to particular cues in similar ways*".

Even though the predictive-based approach is the only one which allows simulating pre-evacuation behaviour, most of the pre-evacuation models employs a priori random or deterministic pre-evacuation times defined by the user [2,6,19,20]. However, different predictive-based models have been proposed [17–20]. These models are generally inspired by behavioural theories but they are not data-driven since they are not based on a regression of actual observed data. Then, their calibration appears a very complex issue that has not yet been addressed.

The main goal of this paper is, therefore, to improve the accuracy of predictions of evacuation models by presenting a novel approach to estimate predictive-based sub-models for the simulation of pre-evacuation states (i.e. normal, investigating, and evacuating). This approach is supported by the Random Utility Theory (RUT), which provides a well-defined calibration formulation [21–23]. Moreover, the models estimated using this approach result closer to the conceptual theories describing pre-evacuation behaviour [15,14] since their aim is to simulate the most important decision-making process affecting the pre-evacuation behaviour, namely the one defining the passage among pre-evacuation states.

This paper presents an overview of the novel modelling approach used to simulate pre-evacuation behaviour and its underlying assumptions. A case study of the proposed modelling approach is presented performing a model calibration using a data set from unannounced evacuation trials carried out in a cinema theatre in Sweden involving a total of 571 participants [10,24]. The main factors affecting pre-evacuation time in the case study are presented. The predictive capabilities and limitations of the modelling approach are also discussed.

2. Model and assumptions

This work proposes a new predictive-based modelling approach. Agent behaviour is defined by three behavioural states inspired by those proposed by Reneke [17], namely, normal, investigating and evacuating. The passage from these states is identified by the decision to start investigating and to evacuate by using the RUT. The probabilities concerning these choices are functions of factors characterizing the social/physical environment and factors characterizing the occupant (i.e. internal and external factors).

The detailed list of assumption behind the proposed model can be summarised with the following list:

(1) *An occupant can have three different behavioural states:*
   a. *Normal State (NS)*
   b. *Investigating State (IS)*
   c. *Evacuating State (ES)*
   This assumption is based on the model proposed by Reneke [17], in which those three behavioural states are recommended to help classifying pre-evacuation behaviour. An occupant is in his/her NS if s/he is performing his/her pre-emergency activities whereas s/he is in his/her IS if s/he has started investigating. Finally, the occupant is in his/her ES when is performing all the activities aimed to evacuate the building.

(2) *The passages allowed are those from NS to ES, from NS to IS and from IS to ES. These passages are irreversible.*
   This assumption argues that once an occupant decides to start evacuating, s/he cannot take the decision to come back to NS or IS. At the same time, once an occupant decides to start investigating, s/he cannot come back to NS (see Fig. 1).
   Moreover, this assumption argues that the passage from NS is not a condition *sine qua non* to pass to ES (see Fig. 1). It is worth discussing that this is a modelling assumption and not a behavioural assumption. In fact, several behavioural studies in emergencies (i.e. [15,14]) argue that investigation is a required step before taking the decision to evacuate. However, both the time and the efforts spent by an occupant to investigate could be very short (i.e. investigation can happen in a time shorter than the model time-step). In those occasions, they may be ignored during the modelling stage.

(3) *Occupants involved in evacuation behaves rationally and their passages from NS to ES, from NS to IS and from IS to ES are ruled by binary decision-making process.*
   This assumption is supported by experimental and theoretical studies [14,25] claiming that irrational behaviour, i.e., 'panic' behaviour, is extremely rare during emergencies. Assuming the rationality of the occupants means that their behaviour is the result of a decision-making process which result is the action to take according to the perceived status quo. According to Kuligowski [26], the decision-making process, meant as the series of steps required to make a decision, is the results of three different phases: Perception, Interpretation, and Decision-Making. The two decisions assumed to make occupants change their state are the decision to investigate and to evacuate. The former makes occupant pass from NS to IS whereas the latter from IS or NS to ES.

(4) *The decision-making process Is affected by both environmental (external) and occupant (internal) factors.*
   This assumption argues that an occupant takes the decision to evacuate considering the perceived actual situation. However, these decisions can be influenced by the occupant characteristics (e.g. previous experience, physical and mental condition, alertness, etc.) since these internal factors can influence the way in which an occupant perceives, interpret and make a decision [26].

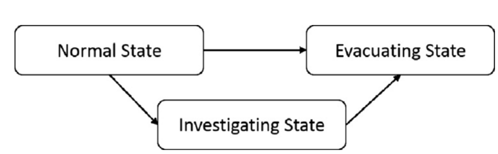

Fig. 1. Proposed behavioural states based on Reneke's model [17].