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A mixed logit model for predicting exit choice during building evacuations

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ABSTRACT

Knowledge on human behaviour in emergency is crucial to increase the safety of buildings and transportation systems. Decision making during evacuations implies different choices, of which one of the most important concerns is the escape route. The choice of a route may involve local decisions on alternative exits from an enclosed environment. This study investigates the effect of environmental (presence of smoke, emergency lighting and distance of exit) and social factors (interaction with evacuees close to the exits and with those near the decision-maker) on local exit choice. This goal is pursued using an online stated preference survey carried out making use of non-immersive virtual reality. A sample of 1503 participants is obtained and a mixed logit model is calibrated using these data. The model shows that the presence of smoke, emergency lighting, distance of exit, number of evacuees near the exits and the decision-maker and flow of evacuees through the exits significantly affect local exit choice. Moreover, the model indicates that decision making is affected by a high degree of behavioural uncertainty. Our findings support the improvement of evacuation models and the accuracy of their results, which can assist in designing and managing building and transportation systems. The main aim of this study is to enrich the understanding of how local exit choices are made and how behavioural uncertainty affects these choices.

1. Introduction

Reducing the number of fatalities and injuries during evacuations from buildings and transportation systems is the main aim of fire safety engineering. This goal can be achieved by designing evacuation systems and procedures so that the time needed by evacuees to escape safely (required safe egress time) is shorter than the time from ignition to the moment when the conditions of the given environment become untenable (Available Safe Egress Time). To date, several evacuation models have been developed to estimate the required safe egress time simulating human behaviour in fire (Gwynne et al., 1999; Kuligowski et al., 2010).

The evacuees' behaviour can be seen as the result of a hierarchical decision-making process entailing three stages: (1) *strategic* (choice to go towards a safe place); (2) *tactical* (choice of routes and exits) and (3) *operational* (short-range choices

Abbreviations: IBU, intrinsic behavioural uncertainty; PPBU, perceptions and preferences behavioural uncertainty; ED, efficient design; MLM, mixed logit model; MNL, multinomial logit; RP, revealed preference; RUM, random utility model; RUT, random utility theory; ST, stated preference.

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concerning the interaction with obstacles and other evacuees) (Lovreglio et al., 2014, 2015a, 2015b). The literature argues that escape route (i.e. tactical choices) can determine the effectiveness of the evacuation process in a crucial way (Ronchi, 2012; Nilsson, 2009; Lovreglio, 2014; Fridolf et al., 2013; Huang and Guo, 2008; Lo et al., 2006; Zheng et al., 2009; Gwynne et al., 2001; Heliövaara et al., 2012). From a modelling point of view, the decision concerning the route to a safe place entails global and local choice (Ronchi and Nilsson, 2016). In fact, evacuees try to select the final goal(s) of their 'evacuation journey' through the global exit choice and then they try to achieve the selected goal making local exit choices. For example, the final/global goal could be to reach a specific exit of a building, whereas the local exit choices are made to pursue the final/global goal. However, although evacuees can be familiar with the building, it is not always realistic to assume that they have a complete knowledge of the global escape route. There could be situations in which the global evacuation route may be the consequence of local choices, as different local exits from the same environment may lead to very different global escape routes (Gwynne et al., 2001; Wagoum et al., 2011).

Several environmental, social and personal factors can affect the global and local exit choice during emergencies (Lovreglio et al., 2014). The most influential environmental factors are (a) distance from the exits, (b) fire conditions (e.g. visibility of an exit; presence of smoke or flames close to an exit) and (c) emergency lighting (Nilsson, 2009; Ronchi et al., 2012, 2015; Gwynne et al., 2000). Different types of social influences can also affect exit choice leading to different behaviours: *herding behaviour*, *leader–follower behaviour*, *cooperative behaviour* and *competitive/selfish behaviour* (Lovreglio et al., 2014, 2016). These social behaviours have been interpreted qualitatively using several theories: (1) the *role–rule theory*, explaining the behaviour based on the behavioural rules of the evacuees, which depend on their daily roles (e.g. staff of a transportation system may react differently from the users) (Canter et al., 1980; Tong and Canter, 1985); (2) the *affiliative theory*, focusing on the decision-maker's attitude to follow familiar evacuees (Sime, 1985); (3) the *social influence theory*, arguing that other evacuees are a source of information (*informational social influence*) and the decision-maker aims to conform his/her choice to that of other evacuees, to avoid their negative judgment (*normative social influence*) (Nilsson and Johansson, 2009) and (4) the *social proof theory*, according to which a decision is considered correct by the decision-maker, because other evacuees have already taken it (Cialdini, 1993). Besides the environmental and social factors, personal factors can affect exit choice. The most influential personal factor is the familiarity of the decision-maker with an exit (*affiliation behaviour*) (Sime, 1985; Shields and Boyce, 2000; Nilsson et al., 2008; Toyama et al., 2006; Fahy et al., 2012; Proulx, 1993; Wagoum, 2012). Furthermore, physical ability (depending on age or health), handedness and socio-psychological characteristics (for instance, direct or indirect risk perception, cultural background or training and past experience) can affect the exit choice (Lovreglio et al., 2014; Ronchi et al., 2012; Wagoum, 2012; Nilsson et al., 2009; Veeraswamy et al., 2011).

A key issue in modelling and designing for evacuations is generally a lack of consideration of the stochastic nature of human behaviour (Ronchi et al., 2013; Lovreglio et al., 2014). The behavioural uncertainty is due to two sources of randomness: the 'intrinsic behavioural uncertainty' (IBU) and the 'perceptions and preferences behavioural uncertainty' (PPBU). IBU is based on the facts that (a) the choices taken by different decision-makers perceiving a situation in the same way may be different and (b) the same decision-makers could choose different exits when they face the same situation at different times. PPBU is related to different decision-makers' perceptions (i.e. different decision-makers can have different quantitative estimates of the same factor) and preferences (i.e. a certain factor may have different importance to different evacuees) concerning the factors affecting the choice. Therefore, behavioural uncertainty represents a key feature that needs to be included in evacuation models. In order to enrich the understanding of how behavioural uncertainty may affect the decision-making process, further studies are necessary.

Here, a case study of local exit choice during an evacuation from an enclosed environment with two exits is presented. This study investigates the effect of both environmental and social factors on exit choice, including the presence of other evacuees, fire conditions, emergency lighting and distance from the exit. The study is based on an online stated preference survey using non-immersive virtual reality scenarios. Responses form 1503 respondents have been collected from all over the world. Choices are modelled using the random utility theory (RUT), which assumes that the decision-maker chooses the alternative yielding the maximum utility and that this utility is not completely known to the modeller, so it has to be considered partially stochastic (Ortuzar and Willumsen, 2011; Train, 2009; Hensher et al., 2005). Therefore, the main aim of this study is to provide new experimental data, which allow expanding and enriching the current understanding of local exit choice in emergencies, and to verify the importance of the behavioural uncertainty in local exit choice.

The study begins with an introduction of existing approaches to model exit choice, supporting the use of the RUT and discussing the underpinning assumptions (Section 2). Section 3 introduces the methodological steps used in the case study. The survey is presented in Section 4, which provides details on the design and administration of the questionnaire and the obtained sample. The proposed exit choice model is introduced in Section 5 and discussed in Section 6, including a sensitivity analysis of the model. The conclusions in Section 7 discuss the practical implications of our study and future works.

2. Methodological issues

Different approaches have been adopted to model exit choice (Kuligowski et al., 2010). Section 2.1 provides a general overview and supports the use of the RUT in this study. The modelling assumptions underpinning the RUT are introduced in Section 2.2, where models using the RUT are reviewed to justify the need for new model specifications/calibration.