Safety Science 106 (2018) 1–9

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Incorporating intelligence for typical evacuation under the threat of fire spreading

Mohammed Mahmod Shuaib

College of Shari'a and Islamic Studies, Department of Computer and Information Sciences, Imam Mohammad Ibn Saud Islamic University, AlAhsaa 31982, Saudi Arabia

ARTICLE INFO

Keywords:
Evacuation
Fire spreading
Decision-making
Exit-choice
Precaution time

ABSTRACT

Having to escape from a moving threat, such as a fire, is a tremendously frightening event during an evacuation. Evacuees' decisions in such circumstances could be better made with an awareness of fire dynamics and potential risks. Rationality is a human factor which has an essential role in accomplishing typical evacuation in emergency situations. In this article, the authors propose a rule-based exit choice model in which the simulated individuals are provided with the assessment of exit's disutility and decision-making capability for selecting and reselecting exits due to the evacuation dynamics. The model allows for the simulation of systematic crowd distribution at exits up until the end of the evacuation process, thereby accomplishing a more efficient evacuation. For further refinement, we allow the individuals to predict the dynamics of the fire spreading and involve its effect on the individuals' assessment. We consider a precaution time for each individual as an essential parameter to guarantee safety from the fire spreading or equivalent risk. Simulations are performed and the discussion of fast and safe decision-making are introduced.

1. Introduction

During fire emergencies, the evacuation of overcrowded pedestrians has resulted in disasters and crowd stampedes, leading to injuries and loss of lives (Keating, 1982; Elliott and Smith, 1993; Mydans, 2009; Luh et al., 2012). Some statistics about fire casualties were further stated in Cao et al. (2014) and Zheng et al. (2017). The psychological, social and political effects of a crowd disaster – despite being relatively rare and with limited deaths – have been significant (Hills, 1998; Sime, 1999). Many aspects affect the success of safe evacuations as well as the total evacuation time, such as disorder and evacuees blocking the exits (Bohannon, 2005). Researchers have been encouraged to consider strategies for improving the evacuation process and preventing the occurrence of such aspects by offering safer pedestrian facilities and understanding the evacuees' behaviors to eliminate the undesirable ones. Crowd managers, for example, are highly motivated to develop decision-support systems and achieve optimal usage of emergency exits in order to prevent the occurrence of aspects that may lead to the negative issues on evacuees' safety (Nilsson et al., 2009; Caroly et al., 2013; Wijermans et al., 2016; Martella et al., 2016). On the other hand, fire safety engineers are focusing mainly on ensuring acceptable building design in order to reduce the time needed for evacuation process (Purser, 2003) and provide an adequate level of safety.

For ethical reasons and other difficulties (Sime, 1999), conducting real experiments involving threatening sources to understand an evacuee's behavior could not be set up. Therefore, researchers were motivated to simulate various evacuation aspects to understand the evacuee's behavior and the resulting interactions. Researchers have developed a large number of simulation models which are separated into two categories. The first one, macroscopic models, are more concerned with the macroscopic behaviors of the whole crowd. These models are often based on traffic flow, queuing theory, or in fluid or continuum mechanics (see e.g. Hughes, 2002). The second category comprises of the microscopic models, which are mainly concerned with the detailed interactions among the pedestrians and their physical environment. Among the variety of microscopic models are the Social Force Model (Helbing and Molnár, 1995); the Cellular Automata Models (Blue and Adler, 2000; Burstedde et al., 2001); the Lattice gas model (Muramatsu et al., 1999; Guo et al., 2013a), which is derived from the CA model; and the Agent-based model (Yang et al., 2011; Zhang et al., 2014; Wang et al., 2015a, 2015b). Researchers have shown that the detailed interactions have major effect on the introduction of the self-organization phenomena and the reproduction of real life data (Helbing et al., 2002; Hoogendoorn and Daamen, 2005; Johansson, 2009; Guo et al., 2012; Shuaib,2014; Shuaib, 2016).

The models' developers have introduced a series of improvements to involve realistic evacuation aspects. Based on theoretical findings in social/architectural studies (Sime, 1985; Canter et al., 1980; Nilsson and Johansson, 2009; Fahy et al., 2012; Proulx, 1993), they have incorporated psycho-social and environmental factors and reproduced its

E-mail address: mmshoaab@imamu.edu.sa.

https://doi.org/10.1016/j.ssci.2018.02.022
Received 10 May 2017; Received in revised form 19 February 2018; Accepted 21 February 2018
0925-7535/

real effects on evacuees' capabilities of steering movement, finding routes, choosing exits, and escaping from threatening sources. Thereby, methods of evacuees' navigation in conformity with several behavioral levels have been implemented (Hoogendoorn et al., 2002; Daamen, 2004; Asano et al., 2010; Kuligowski et al., 2010; Gwynne et al., 2015; Ronchi and Nilsson, 2016). On the other hand, evacuation experiments in order to validate the proposed models have been conducted (Guo et al., 2013a; Cao et al., 2015; Liao et al., 2017; Haghani and Sarvi, 2017); data collection techniques such as virtual reality experiments and surveys have been proposed in order to reproduce virtual data for the purpose of calibration and estimations (Duives and Mahmassani, 2012; Bode and Codling, 2013; Kinateder et al., 2014; Lovreglio, 2014; Lovreglio et al., 2016; Haghani and Sarvi, 2017; Musharraf et al., 2017); different approaches for calibrating the influential components constituting the simulation models have been proposed (Schadschneider et al., 2001; Johansson et al., 2007; Hoogendoorn and Daamen, 2009; Ronchi et al., 2014; Alia and Shuaib, 2014; Li et al., 2015; Lovreglio et al., 2015; Jaber et al., 2018); and evacuation model based simulators have been developed and become a main goal to the researchers to provide protection in pedestrian facilities (see detailed overview in (Kuligowski et al., 2010)).

Despite the aforementioned innovations, fire spreading dynamics and evacuees' responses and interactions with fire are not completely incorporated. Therefore, evacuees' responses associated with risks in emergency scenarios are unexpected. The impact of incorporating the evacuees' rationality and intelligence have not been typically investigated, although rationality and familiarity are the common, dominant and desirable factors in evacuation scenarios (Quarantelli, 1954; Norazahar et al., 2018). We are further motivated by empirical studies which have indicated that involving the evacuees' rationality in emergency situation and their dealing against the emergent threatening sources and their dynamic behaviors are indispensable for introducing representative models (Fahy et al., 2009; Ronchi and Nilsson, 2016; Liao et al., 2017; Norazahar et al., 2018). Note that rationality is a crucial component for modifying efficient decision-support systems (Gwynne et al., 2000; Ronchi et al., 2012, 2015).

In this article, we propose a rule-based exit choice model as a theoretical framework that can implement optimal and safe evacuation and can involve more interactions with fire source and its spreading. In the scenarios adopted here, rationality and intelligence are provided to all simulated evacuees, noticing that rationality and intelligence could be endowed to the evacuees by different instruments, whether computational or not computational instruments, used in crowd management (Gwynne et al., 2000; Nilsson, 2009; Ronchi et al., 2012, 2015; Wijermans et al. 2016; Martella et al., 2016) or by familiarizing the evacuees with the expected aspects of evacuation risks. Rationality is also of great importance for providing way-finding capability for autonomous robot navigation.

The organization of this article is as follows. Section Two presents an overview of exit choice models that involve environmental factors as essential terms in their strategies. In the third section, we propose an exit choice model based on accomplish typical evacuation. The model includes factors enabling the agents to respond intelligently to the dynamics of fire spreading. In section four, simulations to trace the qualitative behavior of the agents and to verify the model are performed.

2. Decision making aspects and exit choice models

The underlying assumption of exit choice behavior with the presence of threatening sources (such as fire, gas, smoke) in the evacuees' environment is that the evacuees are expected to search for the typical emergency exit among alternative exits for safe evacuation. This underlying assumption has been considered by providing agents with long-ranged awareness of exits located within their sights, ability of investigating the factors influencing the assessment process of choosing the best exit, and decision making capability to direct the motion toward the chosen exit. One approach involving exit choice behavior in simulation models is to integrate the assessment process of exits into the adopted navigation method for the agents. In that way, comprehensive navigation method, characterized by instantaneous decisions (operational level), is created. In the CA model, for example, several methods of computing potential floor fields have been introduced for representing exit choice behavior (the CA model is a discrete model in time and space, where the space is a lattice of cells, and the agent's movement from one cell to the adjacent cell is governed by transition probability function determined by rules (Blue and Adler, 2000)). With static floor field the potential of each lattice cell is influenced by the distance to exits and in turn it affects the transition probability of an agent to move to the adjacent cells. Other methods of computing potential floor fields have been introduced to incorporate further factors such as pedestrian congestion (Kretz, 2009; Hartmann, 2010; Alizadeh, 2011; Zhang et al., 2012); route capacity and pedestrian distribution (Zhao and Gao, 2010; Xu and Huang, 2012; Guo and Huang, 2011; Guo et al., 2013b); as well as obstacles (Huang and Guo, 2008) and threatening sources (Zheng et al., 2011; Zheng et al., 2017).

The authors of this article believe that comprehensive navigation is mismatched with real exit choice behavior. Basically, the immediate interaction, in many situations, enforces a high degree of attention and therefore the evacuee becomes unconscious of the detailed behavior of events located beyond his short-ranged perception, although he keeps in his memory the preferred velocity and direction toward the chosen exit. Therefore, exits located within his long-ranged awareness of an individual does not play a role on the operation of avoiding collision or overtaking another evacuee hindering his motion. The authors believe that exit choice behavior is a matter of decision making aspects belongs to strategic or tactical level behavior and results in preferred speed and direction toward the preferred exit, which are involved in the operational navigation process.

Within this context, exit choice models have been developed independent on the navigation method implemented in the evacuation simulation model. Among of which are applied to the CA Simulation models, such as game–theory based models, where rationality is a underpinning assumption. Lo et al. (2006) proposed non-cooperative game strategy which enables each agent to select the best exit based on minimizing the escape time computed with respect to crowd density at the exit, the width of the exit, and the distance to the exit. Ehtamo et al. (2008) introduced a game model where selecting the fastest exit (the sum of estimated moving time and estimated queuing time) is the best response action of the evacuees taking into account smokiness, familiarity and visibility of exits as constraints. Braglia et al. (2013) proposed non-cooperative response strategy considering the dynamic interaction of people with respect to the congestion state of the exits and the actions of other evacuees. Huang and Guo (2008) proposed a logit-based exit choice model, in which a decision of selecting exit is produced by a probability function in terms of distance estimated by a static floor field. Guo and Huang (2010) used logit-based formula in terms of stochastic disutility composed of distance and exit's congestion to calculate the probability of choosing an exit. The exits are grouped in sets with respect to visibility, familiarity, and blocked or hindered exits by threating sources, and the latter group is excluded from consideration. Duives and Mahmassani (2012) further incorporated the angular deviation, total number of evacuees and decision-maker handedness in their modified multinomial logit model. Lovreglio et al. (2014b, 2016) improved stochastic Mixed Logit Model based on random utility theory. The authors investigated more factors such as the presence of smoke and the emergency lighting, and studied the effect of the behavioral uncertainty degree on selecting exits.

Ben et al. (2013) proposed an agent-based exit choice model to study the evacuees' behaviors with respect to several combinations of order activity areas and obstacles. With a similar physical environment to that of the CA model, Zhang et al. (2014) proposed a multi-agent based evacuation model, in which the action direction of each agent is