Safety Science 77 (2015) 57–65

Contents lists available at ScienceDirect

Safety Science

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

Development of a smoke effect model for representing the psychological pressure from the smoke

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ARTICLE INFO

Article history:
Received 31 March 2014
Received in revised form 30 January 2015
Accepted 24 March 2015
Available online 7 April 2015

Keywords:
Evacuation
Psychological pressure from smoke
Human–smoke interaction force

ABSTRACT

Both microscopic and mesoscopic models use Helbing's movement model for estimating the characteristics of an evacuation. Because Helbing's movement model does not consider the effect of smoke, the influence of smoke on walking speed and the toxic gas effect of the combustion gas were used for applying the smoke effect on human behavior. However, these models cannot consider the psychological pressure on evacuees when the evacuees are confronted with the smoke or move through the smoke.

Therefore, we developed a smoke effect model for representing the psychological pressure experienced when the evacuees are confronted with smoke or they move through the smoke. This developed smoke effect model is applied on FDS+Evac which can simulate the fire and evacuation simultaneously. We then analyzed the characteristics of evacuation such as evacuation time, walking speed, and direction, and the psychological pressure from smoke with applying the new smoke effect model. As a result of analysis, when the human–smoke interaction force is additionally applied, the characteristics of evacuation are more reliable than the case of considering the smoke effects on the walking speed and the life or death of evacuees only. However, additional studies for a more reliable psychological factor of the evacuees are required for improving the reality of the modified movement model.

1. Introduction

Evacuation models, which can analyze the characteristics of evacuation behavior in terms of the interaction between a person and other people, and between a person and environment, have been developed to reduce damage to human life (Langston et al., 2006). Also, the importance of the assessment of evacuation safety is being emphasized as part of performance-based design (PBD) (Custer and Meacham, 1997) because the PBD of building is being regulated as standard practice for reducing property damages and casualties. SFPE handbook (Nelson and Mowrer, 2002) suggested a hand calculation model for calculating evacuation time during a building fire. However, the accuracy of the result for this model is limited because the model assumes that all evacuees start the evacuation at the doorway to the emergency stair (Kuligowski and Peacock, 2005). Therefore, various studies for developing evacuation models have been performed to improve the reality and accuracy of evacuation models.

The evacuation models which have recently been developed can be categorized as macroscopic, microscopic, and mesoscopic models according to the modeling method used for the movement of the evacuees (Helbing, 1998). Macroscopic models use a simplified movement model without considering the physical and psychological interaction between evacuees (Klüpfel et al., 2000; Langston et al., 2006; Hamacher and Tjandra, 2002; Helbing, 1998). Both microscopic and mesoscopic models use Helbing's movement model (Helbing et al., 2000) for estimating the characteristics of the evacuation. The characteristics of evacuation can be estimated by considering the interaction between person and other people, and between person and environment because the Helbing's movement model includes the interaction forces between a person and other people, and between a person and a wall. Recently, as high-performance computing has become more available, the development of microscopic/mesoscopic models that predict the evacuation characteristics in terms of the behavioral characteristics of evacuees has increased more than the development of macroscopic models to improve the reality and accuracy of evacuation models (Klüpfel et al., 2000; Langston et al., 2006; Hamacher and Tjandra, 2002).

However, the Helbing's movement model cannot consider the fire effect on the evacuation movement. Therefore, additional models are required for considering the effects of the fire due to the fire source and the smoke. The effect of the fire source is that the evacuees change the evacuation direction to avoid the fire source

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http://dx.doi.org/10.1016/j.ssci.2015.03.019
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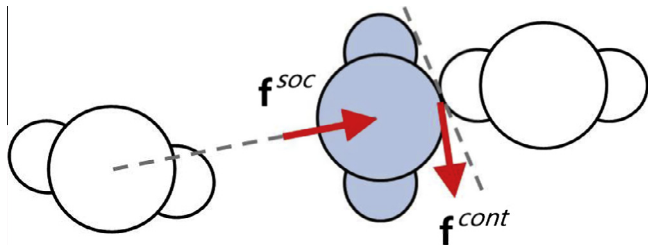

Fig. 1. The schematics of the definition of the social force ($\mathbf{f}^{soc}$) and contact force ($\mathbf{f}^{cont}$) of the agent (Korhonen and Hostikka, 2009).

because of radiative heat from the fire source. Recently, to consider the effect of the fire source, Bae and Ryou (submitted) suggested a radiation repulsive force for representing the psychological pressure experienced when a person is confronted with a fire. Also, evacuees change the characteristics of behavior such as walking speed, direction, and herding behaviors, when they move through the smoke. Jin (2002) suggested the relation between the extinction coefficient and the walking speed by performing an experimental study in the low smoke density condition (below 1.15 1/m by extinction coefficient). Frantzich and Nilsson (2003) performed experiments with the extension of the smoke density range, from 2 to 8 1/m, according to the extinction coefficient. They also suggested the linear relationship between the extinction coefficient and walking speed. Purser (1995) suggested the Fractional Effective Dose (FED) model which is represented as the toxic effect of CO gas and the hypoxia due to the lack of oxygen; he also suggested the criteria for life or death outcomes of an evacuee.

However, most studies on the effect of smoke on the evacuees have focused on the influence of smoke on the evacuee's walking speed (Jin, 2002; Frantzich and Nilsson, 2003) and the toxic gas effect of the combustion gas from fire (Purser, 1995). However, these studies did not demonstrate the psychological pressure of evacuees when they are confronted with the smoke or they move through the smoke. That is, because the effect of psychological

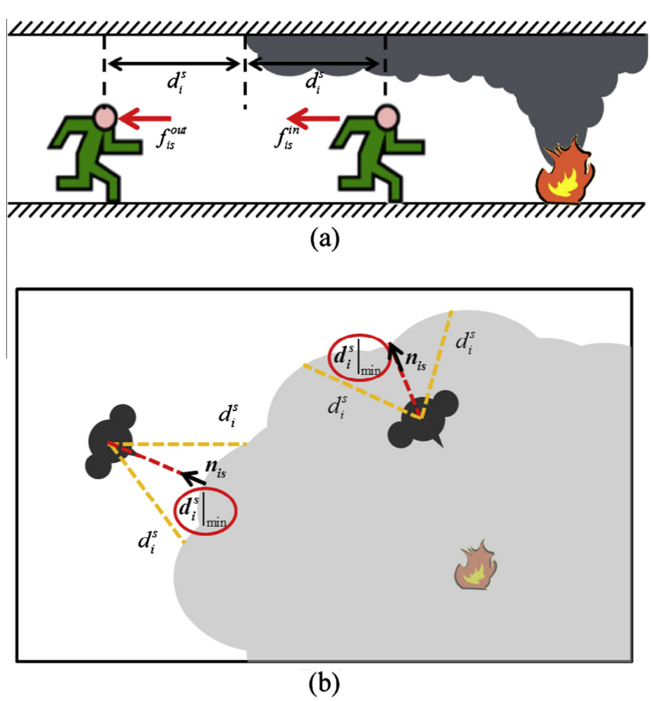

Fig. 2. The definition of the human–smoke interaction force (a), and the distance between human and the smoke boundary (b).

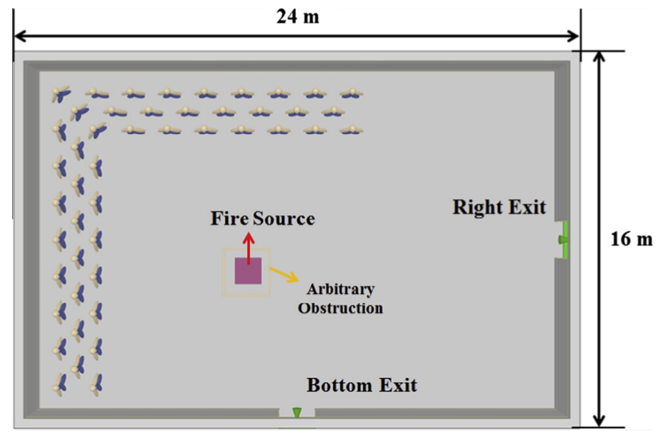

Fig. 3. The Computational domain for simulating the fire and the evacuation.

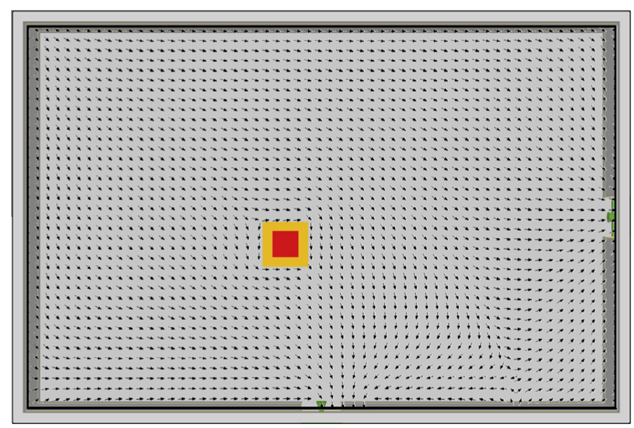

Fig. 4. The desired direction at all positions in the computational domain.

Table 1
The simulation conditions for the fire and the evacuation.

	Case 1	Case 2
Fire grid size	0.2 m	
Fire growth	Ignored	
Fire size	2 MW (toluene)	
No. of evacuees	0.4 m	
Evacuation grid size	47	
Smoke influence	Smoke influence on walking speed and FED model	Smoke influence on walking speed and FED model
Movement model	Without the human–smoke interaction force	With the human–smoke interaction force

Table 2
The characteristics of behavior for adult males who are applied in the evacuation simulation.

	Minimum	Maximum	Mean
Velocity	1.2 m/s	1.2 m/s	1.2 m/s
Pre-evacuation time	0.0	1.0	–
Detection time	0.0	1.0	–

pressure is not considered in these models, unrealistic results are simulated that imply that all evacuees move through the predetermined path regardless of the smoke movement around them; however, evacuees change their evacuation path as a result of the psychological pressure they experience when they are confronted with the smoke (Proulx and Fahy, 2008).