Agent-based Modeling of Indoor Evacuation Behavior under Stressful Psychological State

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Abstract: This paper presents an agent-based model focusing on occupant's locomotion under stress, so as to study the impact of psychic stress on evacuation efficiency. In our model, the occupant's stress is determined by factors including the moving velocity and distance to the exit, the psychological feature of stress resistance capability, and emotional contagion. The occupant's evacuation behaviour in a stressful psychological state is attained as an emergent function of stress-related desire intensity and interaction force based on the Helbing social force model. Through a series of simulations using the proposed model, it is concluded that the increase in the occupants' stress level does reduce the evacuation efficiency; the emotional contagion performs either a panic effect or a calm-down effect which affects the evacuation efficiency negatively or positively; intensive emotional contagion will significantly affect the occupant's stress level and lead to remarkable variation in evacuation time; population structure has an influence on the evacuation efficiency in respect to the occupant's capability of stress resistance. The conclusions indicate that proper control of psychic stress during emergency evacuation is critical for improving evacuation efficiency.

1 INTRODUCTION

When an emergency occurs in a building, the occupants have to evacuate within a very limited time, which results in a stressful psychological state (Wood, 1979). Such stress will remarkably affect the occupants' behaviours and movements. For example, occupants usually increase the speed of their actions and become less patient due to the time pressure. Also, the stressful psychological state would affect accurate information processing and decision making for quick exiting (Proulx, 1993; Pelechano and Malkawi, 2008). These impacts are supposed to have influence on evacuation efficiency. Therefore, the goal of this paper is to present an agent-based model focusing on occupant's locomotion when being in a stressful state, so as to study the impact of psychic stress on the evacuation efficiency.

2 RELATED WORKS

There has been much work done for computational simulation of evacuation behaviour using different method. Earlier researches mainly focus on the physical aspect of evacuation behaviour, such as the fluid-dynamic model (Hughes, 2002), cellular automata (CA) (Kirchner and Schadschneider, 2002, Nishinari et al., 2003), and the social force model (Helbing et al., 2000, Helbing and Molnar, 1995). These models are prominent in simulating the individual's physical movement, but consider very simple, if any, psychological factors.

As the necessity of considering psychological factors has been highlighted (Zheng et al., 2009; Kobes et al., 2010), more efforts are put into incorporate mental state and emotional interaction (Papelis et al., 2011; Zoumpoulaki et al., 2010). Meanwhile, agent-based models are getting famous for simulating heterogeneous population with different social roles and psychological features (Pelechano, 2005; Pan, 2006; Wu and Lin, 2012). However, these researches mainly focus on the impact on decision making such as route choice (Ozel, 2001), while the impact on locomotion seems to be neglected. Besides, the modelling of stress growing and the effect of emotional contagion is still inadequate in current simulation of evacuation behaviour, although several works have been carried out in the field of psychology (Proulx, 1993; Bosse et al., 2009).

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In this paper, we focus on the stress impact on occupant's locomotion during building emergency evacuation. The modelling of psychic stress is incorporated with the concept of social force based on the Helbing model (Helbing et al., 2000) so as to obtain an improved simulation of indoor evacuation.

3 AGENT-BASED MODELLING

3.1 Modelling Framework

The main motivation of our work is that the stressful psychological state caused by an emergency will impact occupant's moving behaviour and evacuation efficiency. Figure 1 shows the framework of the proposed model. The stress level, which is raised by the emergency situation, affects the intensity of movement desire and interaction force with others. The movement in turn impacts the occupant's stress level according to the moving efficiency and the occupant's capability of stress resistance. In our model, the occupant's movement is treated as a set of basic movement rules based on the theory of social force. The stress level is modelled as an emergent function of self-generated stress and the influence by emotional contagion.

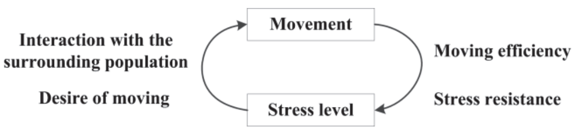

Figure 1: Interaction of occupant's movement and psychic stress.

3.2 Basic Movement Rules

In the proposed agent-based model, the geometric space is represented as finer grids (Song et al., 2006). The grid size is approximately 16.7cm × 16.7cm. Each occupant is simulated as an agent which occupies 3 × 3 grids. The basic movement rules of agent are developed based on social force (Helbing et al., 2000). At each time step, the agent selects one of the eight possible directions to move into with different transition probabilities (Figure 2).

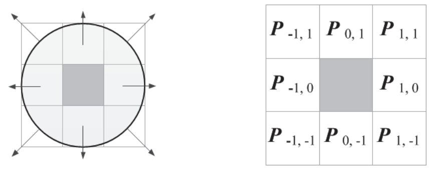

Figure 2: Possible transitions for an agent and associated probability $P_{i,j}$.

The transition probability $P_{i,j}$ is determined by the agent's desired movement, interaction with the surrounding agents and constructions, as well as the inertia force. So it is given by:

$$P_{i,j} = N\,(D_{i,j} + \sum F_{i,j} + I_{i,j})\,\delta_{i,j} \qquad (1)$$

Here $D_{i,j}$ is the intensity of the agent's movement desire in direction (i, j), which reflects the influence by self-adaptive force. $F_{i,j}$ is the influence of the interaction force, which might be either negative or positive. $I_{i,j}$ is the enhancement on the agent's previous movement direction as a result of inertia. $\delta_{i,j}$ denotes the availability of direction (i, j). The direction is available ($\delta_{i,j} = 1$) if the intensity of desired movement overcomes the interaction force and the agent occupies enough space after the movement, saying more than six grids. Otherwise, the direction is unavailable ($\delta_{i,j} = 0$). N is the normalization factor to ensure $\sum_{(i,j)} P_{i,j} = 1$.

As for indoor evacuation, the agent's desired movement should be towards the exit. In this model, since there are eight potential moving directions, the desired movement is projected to the three closest directions, as shown in Formula (2) and Figure 3(a).

$$D_{i,j} = D\cos\theta_{i,j} \qquad (2)$$

Here $D_{i,j}$ is the projection of desired movement D in direction (i, j). $\theta_{i,j}$ is the angle between $D_{i,j}$ and D.

The interaction force, which includes repulsion and friction, is simulated through the overlapping grids among agents and between the agents and the constructions. The impact of interaction force on the transition possibility is shown in Figure 3(b) corresponding to formula (3).

$$F_{i,j} = F\cos\gamma - \mu F\sin\gamma \qquad (3)$$

Here $F_{i,j}$ is the change of transition probability in direction (i, j) resulting from interaction force. F is the average interaction force of the overlapping agents. Parameter μ is the friction coefficient. γ is the angle between F and $F_{i,j}$.

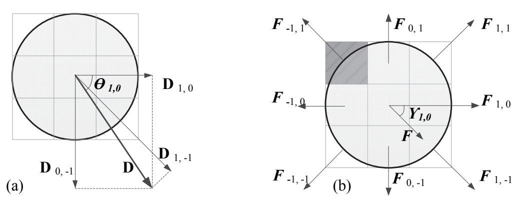

Figure 3: (a) Projection of the desired movement. (b) Interaction force generated by overlapped grid.

3.3 Coping with Stress

According to the previous researches, it is important to model the following observations to simulate human behaviour in stressful situation:

(1) The stress level depends on the occupant's perception of current situation (Proulx, 1993). Moving with higher velocity and getting close to the exit indicate a safer situation and reduce the stress.

(2) The increase in stress level is related to individual's capability of stress resistance. People who differ in personality features might have different psychological reaction in case of an emergency evacuation. Those who have not been properly trained are more likely to feel stressed due to time pressure (McGrath, 1970, Pelechano, 2005).

(3) The social function of emotional contagion will affect occupant's stress level (Bosse et al., 2009, Hoogendoorn et al., 2010, Tsai et al., 2011). In addition to the physical interaction, people also interact emotionally. The expressions and receptions of emotional state within the crowd might help occupants to calm down or result in an even more stressful psychological state.

Therefore, the self-generated stress level is modelled as a function of the occupant's moving speed and the distance to the exit

$$S_i^0(t) = k_{Si} \exp[-W_v \bar{v}_i(t) - W_d (d_{max} - d_i(t))/d_{max}] \tag{4}$$

Here $S_i^0(t)$ is the self-generated stress level of agent i at time t. $\bar{v}_i(t)$ is the agent's current average moving speed in desired direction. $d_i(t)$ is the agent's distance to the exit and d_{max} is the maximum distance to the exit. W_v and W_d are respectively the weight of influence by the moving speed and the distance to the exit. k_{Si} is the stress increase coefficient which depends on the agent's psychological feature of stress resistance. Higher k_{Si} means the agent is more vulnerable to emergency and will be more stressed under the same situation.

Meanwhile, the stress state propagates among the crowd through emotional contagion. According to (Bosse et al., 2009), emotional contagion is related to five critical aspects, namely the level of sender's emotion, the level of receiver's emotion, sender's emotion expression, receiver's emotion openness, and the strength of the channel from sender to receiver. Therefore, the weighed combined stress level an agent received from the others is

$$S_i^*(t) = \sum_{j \in C} W_j S_j^0(t) \tag{5}$$

Where $W_j = \delta_j \alpha_{ij} / \sum_{j \in C} \delta_j \alpha_{ij}$ is the weight of influence by agent j. δ_j is the expressiveness of agent j and α_{ij} is the channel strength from agent j to i.

Considering the agent's openness ε_i and its self-generated stress $S_i^0(t)$, the stress level of agent i at each time step is given by

$$S_i(t) = S_i^0(t) + [S_i^*(t) - S_i^0(t)] \sum_{j \in} \varepsilon_i \delta_j \alpha_{ij} \tag{6}$$

As a reaction to the psychic stress, occupants tend to have a stronger desire to move towards the exit, thus enhancing the interaction among occupants. In particular, the occupant under stressful state will push hard when blocked by others instead of waiting in queue because of the strong desire to move on, which will lead to inefficient outflow. This further aggregates the blocking, and eventually triggers even more stress and enhance the movement desire and interaction force. Therefore, the stress-related desire intensity and interaction force are defined as

$$D_i(t) = D^0 \exp[S_i(t)/k_D] \tag{7}$$

$$F_i(t) = F^0 \exp[S_i(t)/k_F] \tag{8}$$

Here $D_i(t)$ is the intensity of desired movement of agent i at time t. D^0 is the initial intensity of desired movement, and k_D is the increase coefficient of desire intensity against the stress level. $F_i(t)$ is the interaction force of agent i with other agents and constructions at time t. F^0 is the initial interaction force, and k_F is the increase coefficient of interaction force against the stress level.

4 SIMULATION RESULTS AND ANALYSIS

Here we study a simple but quite common situation, namely the evacuation of 200 occupants from a large room with one exit such as a lecture hall or dance hall. The room size is 15m × 15m and the width of the exit door is 1m. Parameters are set as different values to study their impacts on evacuation time.

4.1 Impact of Interaction Force and Desire Intensity

In our model, the agent's movement is a direct result of movement desire and interaction force. Movement desire is a positive factor that leads the agent towards the exit, while the interaction force including repulsion, friction and extrusion are negative factors opposing the movement. Figure 4 is the curve of evacuation time against the division between the interaction force and desire intensity. It is observed that the evacuation time increases evidently as the value of F/D is getting larger. In particular, the evacuation time is shorter when F/D is less than 1.6. Then it increases dramatically when F/D ranges from around 1.6 to 2.6, and fluctuates slightly when F/D reaches 4.4. This indicates that evacuation rate is reduced when the occupants are getting crowded and the interaction force becomes dominant. When it is extremely overcrowded, the evacuation time reaches a maximum value and does not change a lot as the interaction force increases. According to this, in the following simulations the values of D^0, F^0, k_D, k_F are set to 0.1, 0.15, 0.5, 0.25 to keep the value of F/D within a reasonable range so as to study the impact of stress level on evacuation time.

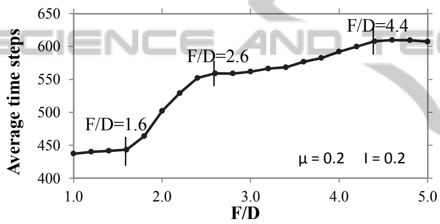

Figure 4: Curve of evacuation time against F/D.

4.2 Impact of Stress Level

In order to observe the impact of stress level on evacuation efficiency, we exclude the influence from emotional contagion among occupants by setting the parameters of the emotion openness ε, emotion expressiveness δ, and the channel strength α to zero.

Figure 5 shows the change of crowd's average stress level plotted against evacuation time with different stress increase coefficient k_S. It is shown that large k_S value results in higher average stress level. It is also observed that at the beginning of evacuation the stress level is rather high, and it is more evident when k_S is large. The reason for this is that stress level is an emergent function of moving velocity and distance to the exit. At the beginning, far distance from the exit causes most of the stress. As the agents are getting closer to the exit, velocity becomes the dominant factor that impacts stress level. When it becomes crowded around the exit, the stress level increases due to inefficient move.

The resulting variation of stress level is supposed to have an influence on evacuation efficiency. Figure 6 shows the change of evacuation time against stress increase coefficient k_S. In general, higher k_S value reduces the evacuation rate and results in longer evacuation time. As we mentioned, the growth of stress will lead to an increase in both desire intensity and interaction force, and it is the division between desire intensity and interaction force that critically affects the evacuation efficiency. If the k_S value is large, the stress level will be more likely to reach the point where the interaction force becomes dominant and evacuation efficiency is reduced because of inefficient outflow.

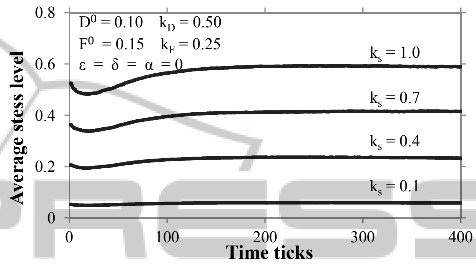

Figure 5: Curve of the crowd's average stress against stress increase coefficient.

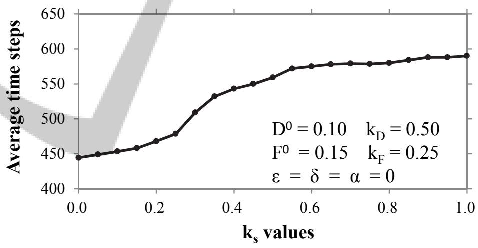

Figure 6: Curve of evacuation time against stress increase coefficient.

4.3 Impact of Emotional Contagion

In order to study the impact of emotional contagion, two types of agents were designed. Agent A has stronger stress resistance capability ($k_{SA} = 0.1$), while Agent B has inadequate stress resistance capability ($k_{SB} = 0.5$). Two typical scenarios are simulated (Table 1). In scenario 1, Agent A acts as receiver fully opened to the emotional stress expressed by the sender Agent B. In scenario 2, the roles of Agent A and Agent B are reversed.

Figure 7 shows the crowd's stress level at a particular time. The number of Agent A and Agent B are the same and the scope of emotional contagion is one meter. Comparing with the simulation without emotional contagion, overall stress level is higher in Scenario 1 because of the stressful emotion sent out by Agent B, while it is much lower in Scenario 2 because of the calm-down effect by Agent A.

The resulting variation of stress level apparently has an influence on evacuation time (Figure 8). It is shown that evacuation time is reduced evidently in Scenario 2. Meanwhile, the gap becomes remarkably as the channel is strengthened, which indicates stronger emotional contagion within the crowd and more impact on the overall stress level.

Table 1: Parameters setting of the two scenarios.

Scenario 1		Scenario 2	
Agent A	Agent B	Agent A	Agent B
$k_{SA} = 0.1$	$k_{SB} = 0.5$	$k_{SA} = 0.1$	$k_{SB} = 0.5$
$\varepsilon_A = 1.0$	$\varepsilon_B = 0.0$	$\varepsilon_A = 0.0$	$\varepsilon_B = 1.0$
$\delta_A = 0.0$	$\delta_B = 1.0$	$\delta_A = 1.0$	$\delta_B = 0.0$

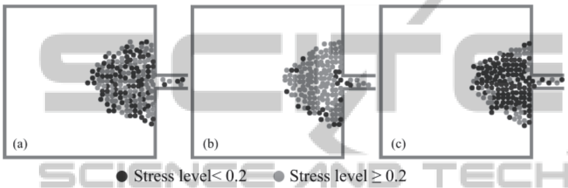

Figure 7: Stress level at the 100th time tick: (a) without emotional contagion, (b) Scenario 1 and (c) Scenario 2.

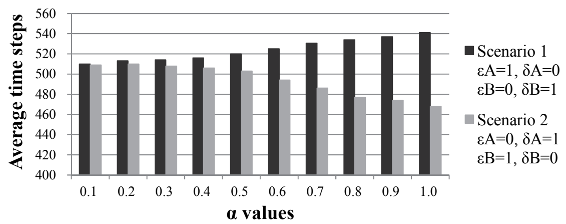

Figure 8: Evacuation time under Scenario 1 and Scenario 2 with different channel strength.

Figure 9 is the curve of the evacuation time against the scope of emotional contagion. It is observed that the evacuation time is further increased in Scenario 1 and reduced in Scenario 2 as the scope of emotional contagion is enlarged. The reason is that with wider emotional contagion scope, one would have emotional interaction with more agents. Therefore, the emotional influence by the surrounding population is enhanced, which leads to stronger panic effect in Scenario 1 and calm-down effect in Scenario 2.

Figure 10 shows the change of evacuation time corresponding to different population structure, where the scope of emotional contagion is set as one meter. It is noted that the population structure has an evident influence on evacuation time in respect to occupant's stress resistant capability. In fact, the overall stress level rises up with higher percentage of Agent B which has more rapid stress increase rate, or lower percentage of Agent A which has slower stress increase rate. This results in increasing evacuation time in Fig. 10(a) and decreasing evacuation time in Fig. 10(b), even without emotional contagion ($\alpha_A = \alpha_B = 0$). Meanwhile, when emotional contagion is taken into account, the increasing number of emotional senders leads to additional panic effect in Scenario 1 and calm-down effect in Scenario 2. Therefore, comparing with the simulation without emotional contagion, the evacuation time generally increases more rapidly as the percentage of Agent B increases in Scenario 1 and decreases more rapidly as the percentage of Agent A increases in Scenario 2.

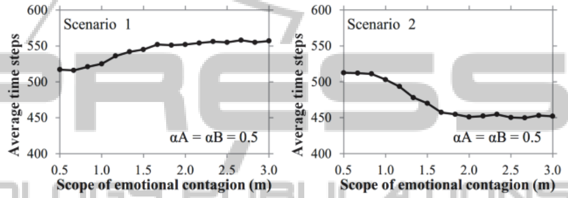

Figure 9: Impact of the emotional contagion scope on the evacuation time.

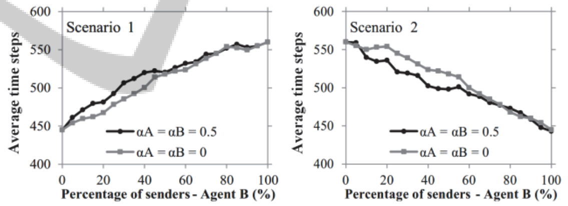

Figure 10: Impact of the population structure on the evacuation time.

5 CONCLUSIONS

In this work we introduced the stress impact in the modelling of occupants' locomotion i building evacuation. From the results of the simulations using the proposed model, the following conclusions can be drawn: (1) The increase in occupant's stress level during emergency evacuation does lead to overcrowding and reduce the evacuation efficiency. (2) Emotional contagion critically affects the crowd's stress level and the evacuation time. The contagion of higher stress level might aggravate the crowd's overall stress and reduce evacuation efficiency, while the contagion of lower stress level performs a calm-down effect and improves evacuation efficiency. (3) The variation of evacuation time is related to the intensity of emotional contagion. If the emotional contagion channel is weak and the scope is small, the influence of emotional contagion on occupants' stress level is limited and the evacuation time will not be significantly affected. (4) The evacuation efficiency is affected by population structure in terms of occupant's capability of stress resistance. With the increase in the number of occupants who are vulnerable to emergent situation, the crowd's overall stress level rises up more rapidly and the evacuation efficiency will be reduced. Therefore, it is essential to control the crowd's stress level for an efficient building evacuation.

Although the model is developed on the basis of some critical observations of human behaviour in emergency situation, a comprehensive validation is still in need. Therefore, we are now working towards developing more complex simulation scenarios so as to further evaluate the proposed model. It is expected that such a model incorporating psychic stress will be able to reflect more reliable indoor evacuation in emergent situation.

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REFERENCES

Bosse, T., Duell, R., Memon, Z. A., Treur, J. & Van Der Wal, C. N. A Multi-Agent Model for Mutual Absorption of Emotions. 2009. Citeseer, 212-218.

Helbing, D., Farkas, I. & Vicsek, T. 2000. Simulating dynamical features of escape panic. *Nature,* 407, 487-490.

Helbing, D. & Molnar, P. 1995. Social force model for pedestrian dynamics. *Physical review E,* 51, 4282.

Hoogendoorn, M., Treur, J., Van Der Wal, C. N. & Van Wissen, A. An Agent-Based Model for the Interplay of Information and Emotion in Social Diffusion. 2010 International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT), 2010. IEEE, 439-444.

Hughes, R. L. 2002. A continuum theory for the flow of pedestrians. *Transportation Research Part B: Methodological,* 36, 507-535.

Kirchner, A. & Schadschneider, A. 2002. Simulation of evacuation processes using a bionics-inspired cellular automaton model for pedestrian dynamics. *Physica A: Statistical Mechanics and its Applications,* 312, 260-276.

Kobes, M., Helsloot, I., De Vries, B. & Post, J. G. 2010. Building safety and human behaviour in fire: A literature review. *Fire Safety Journal,* 45, 1-11.

Mcgrath, J. E. 1970. A conceptual formulation for research on stress. *Social and psychological factors in stress,* 10, 21.

Nishinari, K., Kirchner, A., Namazi, A. & Schadschneider, A. 2003. Extended floor field CA model for evacuation dynamics. *IEICE transactions on information and systems,* 87, 726-732.

Ozel, F. 2001. Time pressure and stress as a factor during emergency egress. *Safety science,* 38, 95-107.

Pan, X. 2006. *Computational modeling of human and social behaviors for emergency egress analysis.* Stanford University.

Papelis, Y., Bair, L., Manepalli, S., Madhavan, P., Kady, R. & Weisel, E. 2011. Modeling of Human Behavior in Crowds Using a Cognitive Feedback Approach. *In:* Peacock, R. D., Kuligowski, E. D. & Averill, J. D. (eds.) *Pedestrian and Evacuation Dynamics.* Springer.

Pelechano, N. 2005. Crowd simulation incorporating agent psychological models, roles and communication. DTIC Document.

Pelechano, N. & Malkawi, A. 2008. Evacuation simulation models: Challenges in modeling high rise building evacuation with cellular automata approaches. *Automation in construction,* 17, 377-385.

Proulx, G. 1993. A stress model for people facing a fire. *Journal of Environmental Psychology,* 13, 137-147.

Song, W., Xu, X., Wang, B. H. & Ni, S. 2006. Simulation of evacuation processes using a multi-grid model for pedestrian dynamics. *Physica A: Statistical Mechanics and its Applications,* 363, 492-500.

Tsai, J., Bowring, E., Marsella, S. & Tambe, M. 2011. Modeling Emotional Contagion. *MABS Multiagent-based Simulation Workshop at AAMAS 2011.*

Wood, P. 1979. *Behaviour Under Stress: People in Fires.* PhD Thesis, Loughborough University of Technology.

Wu, L. & Lin, H. 2012. A personalized spatial cognitive road network for agent-based modeling of pedestrian evacuation simulation: a case study in Hong Kong. *Annals of GIS,* 18, 109-119.

Zheng, X., Zhong, T. & Liu, M. 2009. Modeling crowd evacuation of a building based on seven methodological approaches. *Building and Environment,* 44, 437-445.

Zoumpoulaki, A., Avradinis, N. & Vosinakis, S. 2010. A multi-agent simulation framework for emergency evacuations incorporating personality and emotions. *Artificial Intelligence: Theories, Models and Applications,* 423-428.