Inf Technol Manag (2014) 15:141–149
DOI 10.1007/s10799-014-0185-1

Escape behavior in factory workshop fire emergencies: a multi-agent simulation

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Abstract In this study, a multi-agent simulation is conducted to explore the relationship between fire escape survival rate and occupants' risk preferences and stress capacity. The results indicate that, the escape survival rates for occupants with different risk preferences and stress capacities can be significantly different. More specifically, the simulation shows that the smaller the number of occupants is in a fire, the higher the survival rate can be expected. In addition, the simulation shows that the larger the number of individuals with stronger stress capacities is in a group, the higher the escape survival rate the group has. Moreover, the simulation shows that the more disperse the individuals' risk preferences is in a group, the higher the escape survival rate the group has. Based on the simulation results, the paper proposes a framework of E-evacuation system to guide the rational escape and evacuation when enterprise workshop fire occurs. Suggestions for increasing escape survival rates during fires are provided.

Keywords E-evacuation · Risk preference · Stress ability · Multi-agent system · Fire · Evacuation · Escape survival rate

1 Introduction

Fire is one of the most common emergencies. It may cause huge property damages and casualties, especially in places such as cinemas and factories. In such places, it is extremely hard for occupants to escape. If occupants have not received any escape training before or a well prepared escape plan is not available, they can hardly survive. This is simply because in such emergent conditions, occupants have to make a correct decision right away and take proper actions immediately. The correct escape decision and proper actions in scene of a fire means the difference between life and death.

In the past decades, scholars have explored occupants' decision making and escape behaviors in emergencies. For example, Kelley and Condry [13] find that the more the losses are, the lower the escape survival rate is; and that the bigger a group is, the fewer group numbers escape successfully. They also find that if the behaviors of group members are guided by each other, the escape results will change; and that a positive expression of a group's confidence will substantially increase the group's success escape rate. Helbing et al. [10] explore the irrational characteristics of the group panic escape behaviors in emergencies. Saloma et al. [23] study the self-organized queuing and scale-free behavior in real escape panic. Joo et al. [11] conducted agent-based simulation of affordance-based human behaviors in emergency evacuation. Lv et al. [16] examine evacuation decision-making behaviors and risk analysis under multiple uncertainties in emergencies. Ozbay et al. [18] model the emergency evacuation in Northern New Jersey based on a regional transportation planning tool. Pereira et al. [19] employ a finite automata approach to simulate the evacuation of a congested population in emergency. Sun et al. [29] develop an emergency

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evacuation information system in order to make emergency decision-making more effective. Numerous other authors have studied emergency situations [5, 6, 24, 25, 33, 34, 36].

All of these studies focus on observing occupants' escape behavior characteristics directly. However, they did not pay attention to how occupants' risk preferences and stress capacity impact their escape behaviors. More specifically, few researches explore how occupants' risk preferences and stress capacity impact escape survival rate in fires. Risk preference represents an individual's attitude to risks. Engelmann and Tamir [4] prove that individuals' risk preferences have influences on their decision-making processes with neuroscience methods. Risk preferences can be divided into risk loving and risk avoiding. According to Abrahamsson and Johansson [1], the majority of social emergencies resulting in death are related with risk seeding behaviors. Their further study points out that individual risk preferences are influenced by circumstances and that group risk preferences exist. Stress capacity refers to an individual's ability to deal with stress when he/she encounters critical, complex, and difficult situations [31]. Stress capacity can impact the quality of decision [3] and decision-making process [14, 17]. As such, this paper adopts a multi-agent simulation to simulate occupants' emergency escape decision-making process and actions during a fire in the context of labor-intensive factory workshops. The goal of this paper is to explore the relationship between escape survival rate and occupants' risk preferences and stress capacity.

The rest of this paper is organized as follows: In Sect. 2, background of fires occurring in factory workshops is provided. Occupants' escape behaviors and the main challenges for their decision-making during a fire are discussed as well. Section 3 provides an overview of the multi-agent programming language and modeling environment that this paper adopts to simulate factory workshop fires. Parameters settings are introduced in this section. Section 4 lists the behavior rules for agents in this simulation. In Sect. 5, the operation process of the performed simulation is introduced. Results of the simulation are discussed in Sect. 6. Based on the simulation, a framework of E-evacuation system for enterprise workshop fire emergency is proposed in Sect. 7. At the end, Sect. 8 concludes the whole paper and provides suggestions for increasing escape survival rates during fires.

2 Background

Occupants in factory workshops must have certain risk preferences and stress capacities in order to make the correct decision and take proper actions to escape because fires occurring in factory workshops are very dangerous and might cause unexpected losses. The texture and quantity of materials stored in workshops will affect the speed at which a fire spreads. Specifically, whether the materials in a workshop are flammable and the degree of flammability play important roles in fire spreading speeds: the higher the degree of flammability is, the quicker a fire spreads. For example, textile workshops are usually full of combustible materials. Once a textile workshop is on fire, these materials will cause the fire to spread quickly. As a result, workers have very little time to escape and suffer great pressure. Fires occurring in chemical workshops are more dangerous because other than flammable materials, toxic substances and explosives are usually stored in these places. The opportunity for workers to escape from such fires is pretty slim. In addition, the amount of materials in a workshop can directly affect the spreading speed of a fire and occupants escaping routes. Large amount of materials means many flammable things, long burning time, and large scale of fire. Meanwhile, the stacked material can block occupants escaping routes. This will slow down the escaping speed. Furthermore, the logistic model chosen by a company will affect the inventory in a workshop. Specifically, the options of first-party, second-party or third-party logistics by a company will significantly influence the changing speed of workshop inventory per unit time, which thereby affects the patency of occupants escaping routes. Finally, workshop building design is an important factor that impact workers' escape. The lack of exits will cause congestion during the evacuation in a fire.

According to Chu and Sun [2], how long occupant evacuation last depends on "fire detection and alarm, occupant characteristics (such as age, sex, physical and mental ability, sleeping or waking, and population density), human behavior in fire (such as seeking information, informing others, collecting belongings, and choosing an exit) and building characteristics (such as corridor width, exit numbers and widths), etc." (p. 1126). Occupants' escape behaviors vary in factory workshop fires. For example, on August 27, 2011, Bao Dongsheng Plastic Products Factory in Longgang District, Shenzhen, China was on fire. Disconcerted workers looked for ways to escape. In the chaos, two flustered workers jumped from the workshop building, one dead and another seriously injured. On December 14, 2009, a workshop at a third floor with 45 workers in Runsen Shoe Factory in FuZhou, China caught fire. Because the fire blocked the emergency exit, workers had to go upstairs and jumped from the 4th floor, 14 seriously injured. In contrast, workers in a workshop fire breaking out in Ningbo China escaped successfully by hitting a hole in the wall when the emergency exits was blocked by the fire.

Fire escape behaviors in factory workshops are the results of occupants' decision making that are influenced

Table 1 Main problem in occupants' decision making process in a factory workshop fire

Decision making problems	Initial decision	Subsequent decision
General decision	1. Fight against the fire 2. Escape and evacuation	1. Choose fire fight first, when fire cannot be weakened, even bigger and more dangerous, choose to escape 2. Escape successful and come back to fight against the fire
Self-save and waiting for rescue decision	1. Be active to escape 2. Wait for the rescue	1. Not successful in escape, then wait for the rescue 2. No result in the external rescue, then seek for self-rescue
Channel (exit) selection decision	1. Follow other occupants to escape 2. Choose a nearby exit to flee	When exit is blocked, choose some means, such as smashing windows, hitting hole in walls, to flee through the broken exits

by many variables, such as interactions between the occupants, the building, and the developing fire [22]. Different people have different levels of awareness of what is happening in their surrounding environment [20]. Once they realize that a fire occurs, occupants make their decisions based on the result of their risk assessment. For example, they can put out the fire first and then escape, or escape first and come back later with help to put out the fire, or take an active but risky way to rush out of the fire scene, or just wait for rescue. Table 1 shows the main problems in occupants' decision making process in a factory workshop fire.

The key point is that occupants must make their decisions immediately. Sime [28] points out that delays in occupants starting to move and movement other than escape could be a major feature of human behavior in fires. Shields and Boyce [26] indicate that a primary factor contributing to fire deaths is not travel distance to exits, but delays in warning occupants and extended times before movement commenced. According to Proulx and Sime [21] and Sime [28], the delay in starting positive evacuation actions can be much longer than the time to travel the distances to and through exits. Occupants do not have much time to think over the options listed in Table 1. The condition of workshop can easily boost quick spread fires. Panic occupants will worsen the chaos at fire scene. Even worse, emergency exits might be blocked by fires. In such emergent situations, occupants' individual risk preferences and stress capacities play important roles in their decision-making processes.

Prior research has proved that training, more specifically risk preference and stress capacity trainings, impact individuals' decision making and behaviors in a fire. Fire drill can help occupants make correct decisions and take proper actions during a fire. For example, on April 1, 2010, a 2000 m^2 workshop with 1,078 workers in YierKang Shoe Company in Zhejiang, China was on fire. Thanks to the regular fire evacuation drills, these workers covered wet towels on their mouths, followed the scheduled escape route, and fled the fire in an orderly manner. Fortunately, the fire did not cause any casualty.

3 Simulation and parameters setting

This study conducts a simulation based on Netlogo to explore the relationship between escape survival rate and occupants' risk preferences and stress capacities. NetLogo is a multi-agent programming language and modeling environment for simulating natural and social phenomena [32]. It allows researchers to give instructions to huge number of independent "agents" who are operating concurrently. In this regard, NetLogo can help researchers "explore connections between micro-level behaviors of individuals and macro-level patterns that emerge from their interactions" [32]. Figure 1 shows the interface of the established multi-agent simulation applied in this study. The simulation consists of machinery, equipment, walkways, workshop facades, workshop exits, and safety zones. Suppose that workshop exterior walls, machinery, and equipment are taller than an ordinary person's height and that no one can stand or walk on the top of the machinery, equipment or workshop exterior walls.

The simulated event is a fire that occurred at KPT Fitness Equipment Co., Ltd. in Dongguan China. Established in 1993, KPT has solid experiences in indoor fitness equipment R&D and manufacturing. It specializes in producing electric treadmills, exercise bikes, and elliptical machines. On March 6, 2012, welding sparks ignited a fire in one of its workshop on a second floor. Very soon the fire burned down all windows. Raw materials, such as foam, burned quickly and stuck together. This caused the workshop full of a pungent odor. Although 256 occupants were trapped, they were well organized and escaped in order. Fortunately, they all survived in this terrible fire.

The multi-agent simulation accepts different parameters within a certain range. Therefore, various scenarios in factory workshop fires can be simulated. For example, the position of the start point of a fire is controlled by horizontal axis (Fire-Start-Point-X $\in [-16, 16]$) and vertical axis (Fire-Start-Point-Y $\in [-16, 16]$). The speed at which a fire spreads is controlled by fire spread speed (Fire-Spread-Speed $\in [1, 20]$). People count (People-count $\in [1, 300]$)

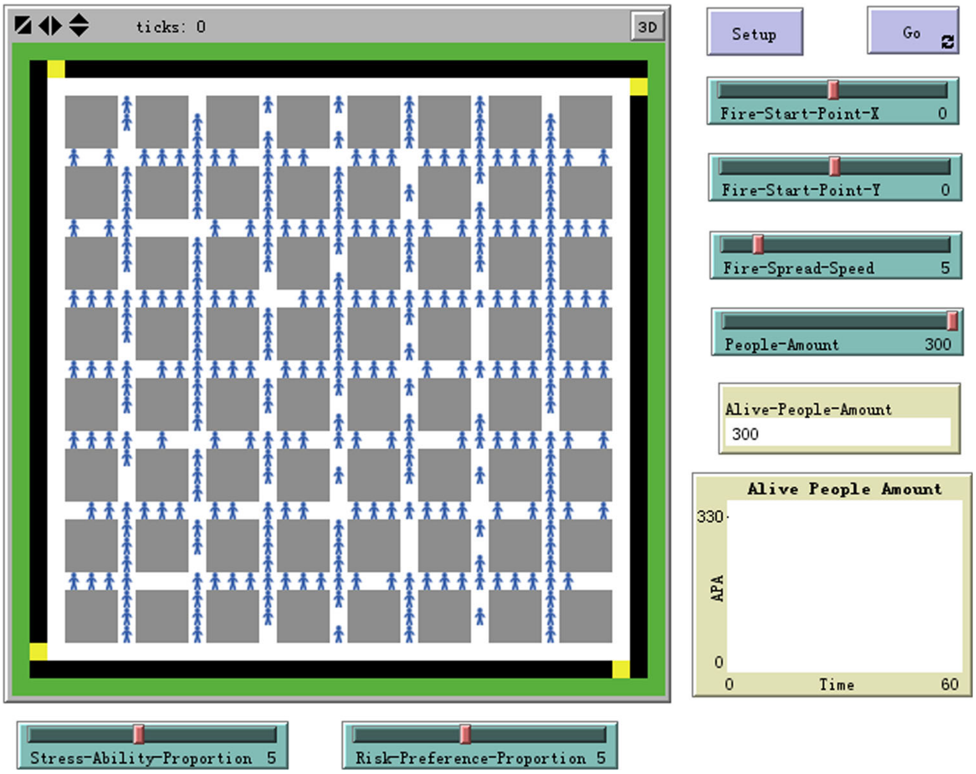


Fig. 1 The interface of system simulation

ticks: 0

Fire-Start-Point-X 0

Fire-Start-Point-Y 0

Fire-Spread-Speed 5

People-Amount 300

Alive-People-Amount 300

Stress-Ability-Proportion 5

Risk-Preference-Proportion 5

represents that the number of occupants that are evenly distributed in the walkways. Stress capacity proportion (Stress-Capacity-Proportion ∊ [1, 10]) is the ratio between the number of occupants with strong stress capacities and the reciprocal of the value of Stress-Capacity-Proportion. Risk preference proportion (Risk-Preference-Proportion ∊ [1, 10]) is the ratio between the number of occupants who are risk loving and the reciprocal of the value of Risk-Preference-Proportion. Results vary if different parameters are set.

4 Behavior regulations for agents

Each unit area in a factory workshop, such as safety zone, exterior wall, exit, walkway, machine, equipment, and other fixed facilities, is set as Patch, whereas each occupant is set as Turtle in this simulation. A Turtle has four attributes, namely life value, risk preference, stress capacity, and escape direction. Risk preference has two values: "0" and "1". The former represents risk loving while the latter means risk avoiding. Similarly, stress capacity has two values: "0" and "1" as well. The former means weak stress capacity and the latter represents strong stress capacity. Escape direction have four values, namely "1", "2", "3", "4". These four values indicate the directions of the exits that occupants head for and they represent northwest, northeast, southeast, and southwest respectively. During a factory workshop fire, occupants' eyesight might be blocked by smoke or equipment easily. In such an urgent situation, it is very hard for them to make correct judgments about what is the shortest way to the nearest exit. In Netlogo simulation, one Patch usually accommodates one Turtle. But in factory workshop fires crowded occupants are trapped in limited spaces. Therefore, in this simulation, a Patch is set to accommodate two Turtles.

Gwynne et al. [9] and Sime [27] point out that instead of heading towards the nearest exit, occupants prefer to move toward other more distant exits with which they have had previous experience and with which they feel more confident. However, in this simulation, if occupants are familiar with all formal exits, those who have strong stress capacity are more likely to calmly observe their surroundings and to find the shortest way to the nearest exit, whereas those who have weak stress capacity tend to run about aimlessly because they randomly choose one exit to escape. In such a case, stress capacity impact occupants' decision processes. However, risk preferences do not have any impact. Therefore, the study first sets the following rules for Turtles' decision making in the simulation:

Rule A1: If Turtles are familiar with all formal exits, those with strong stress abilities choose to escape from the nearest one;
Rule A2: If Turtles are familiar with all formal exits, those with weak stress abilities randomly choose one to escape.

In some cases, alternative exits exist but occupants do not know where they are. Since those with strong stress abilities prefer to find a nearest exit and those with weak stress abilities randomly select an exit, all of them have to face a challenge if their preference is an alternative exit. Alternative exits are not used often and few occupants know how to access them and how they work, so it is very risky to pick an alternative exit during a factory workshop fire whether this exit is a nearest one or a randomly selected one. Due to the risks, alternative exits are not crowded as formal ones. In such a case, risk loving occupants tend to choose alternative exits, whereas risk avoiding occupants prefer formal ones. Combining the effects of stress abilities and risk preferences, the paper continues to set the following rules for Turtles' decision making in the simulation:

> Rule B1: If Turtles only are familiar with formal exits, those risk loving Turtles with high stress capacities choose to escape from the nearest alternative exit;
> Rule B2: If Turtles only are familiar with formal exits, those risk avoiding Turtles with high stress capacities choose to escape from the nearest formal exit;
> Rule B3: If Turtles only are familiar with formal exits, those risk loving Turtles with low stress capacities randomly choose an alternative exit to escape.
> Rule B4: If Turtles only are familiar with formal exits, those risk avoiding Turtles with low stress capacities randomly choose a formal exit to escape.

5 Simulating operation process

Once the parameters are set, the initialization of the simulation is done. In the initialization stage, Patches are built up, including machinery, equipment, walkways, workshop facades, workshop exits, and scenes of safety zones. Preset Turtles are randomly distributed to the walkways. In addition, the attributes of each Turtle are configured based on preset risk preference proportion and stress ability proportion values.

Next, the simulation moves to the running stage. Turtles follow the established rules and select an exit first. On one hand, they need to calculate whether the space in front of a Patch is big enough to accommodate them. If yes, they can move on to the next step. If no, their next movement depends on their positions. For example, if a Turtle is at a crossing, it can choose a different direction. Otherwise, it has to take a step backward. When a Turtle arrives at a target exit, the system will automatically set its location as a safe area. Accordingly, observation on this Turtle is done. On the other hand, Turtles need to figure out the intensity of the fire. The fire will spread at a preset speed, so in a given period of time a Patch will catch fire. When the fire reaches a Turtle's Patch, the turtle's life value will minus 1. If a Turtle's life value is less than 0, the Turtle is dead. The fire can reach any place inside the workshop other than safe areas. When all areas inside the workshop are covered by fire, the simulation ends (Fig. 2).

6 Analysis of simulation results

The simulation has three phases. In phase 1, the goal is to explore how fast the spread speed of fire (FSS) is and the total number of occupants (PA) that impacts the final escape survival rate (APA). So risk preference proportion (RPP) and stress ability proportion (SAP) are both set as 2. Figure 3 shows results of four typical cases, in which FSS are set as 2, 5, 20, and 5 respectively and PA are set as 300, 300, 300, and 150 respectively. All four diagrams indicate that as time goes by during fires, the number of survival occupants declines. This means that the longer fires last, the fewer occupants can survive. According to diagram (1), diagram (2), and diagram (3), lower speeds of fire cause fewer numbers of deaths. Diagram (2) and diagram (4) show that the smaller the total number of occupants is, the higher the survival rate is. Fewer occupants will cause less congestion, so occupants have less troubles and can escape faster. This result proves the finding reported by Kelley and Condry [13].

In phase 2, the goal is to explore how stress capacity ratio impacts the final escape survival rate (APA). Risk preference ratio is the proportion of the risk preferences of individuals in a group. Stress capacity ratio refers to the proportion of the stress capacities of individuals in a group. The two ratios can be calculated after risk preference proportion (RPP), stress ability proportion (SAP), and total number of occupants (PA) are set. In this phase, fire-caught point is set as the start point (0, 0) and spread speed of fire (FSS) is set as 5.

Tables 2, 3 and 4 show three cases, in which SAP are set as 0.1, 0.5, and 1.0 respectively and PA are set as 100, 200, and 300 respectively. Suppose that occupants are familiar with all four formal exits, and that they show the analog value of the escape survival ratio in the group with different individual stress capacity. In each case, the simulation runs ten times and generates ten different values of escape survival rate. The final escape survival rate is the arithmetic average of these ten values. The three tables show that the more individuals with strong stress capacities are in a group, the higher escape survival rate this group has. This is because individuals with strong stress capacities are capable of making independent judgments and choosing a nearest exit, while those with weak stress capacities are not able do so.

When high stress ability proportion of individuals is close to 100 %, the highest ratio of escape survival can be

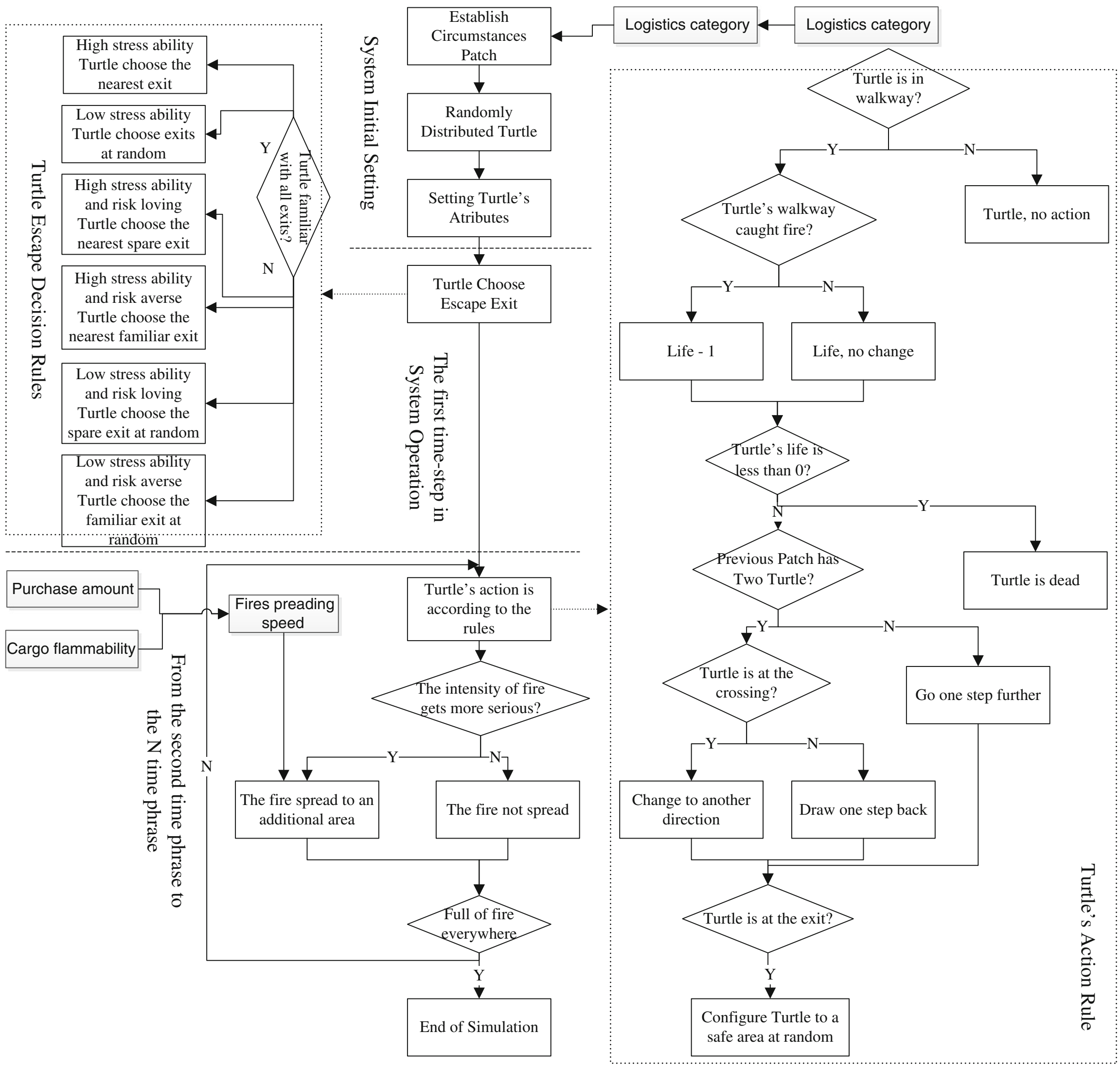


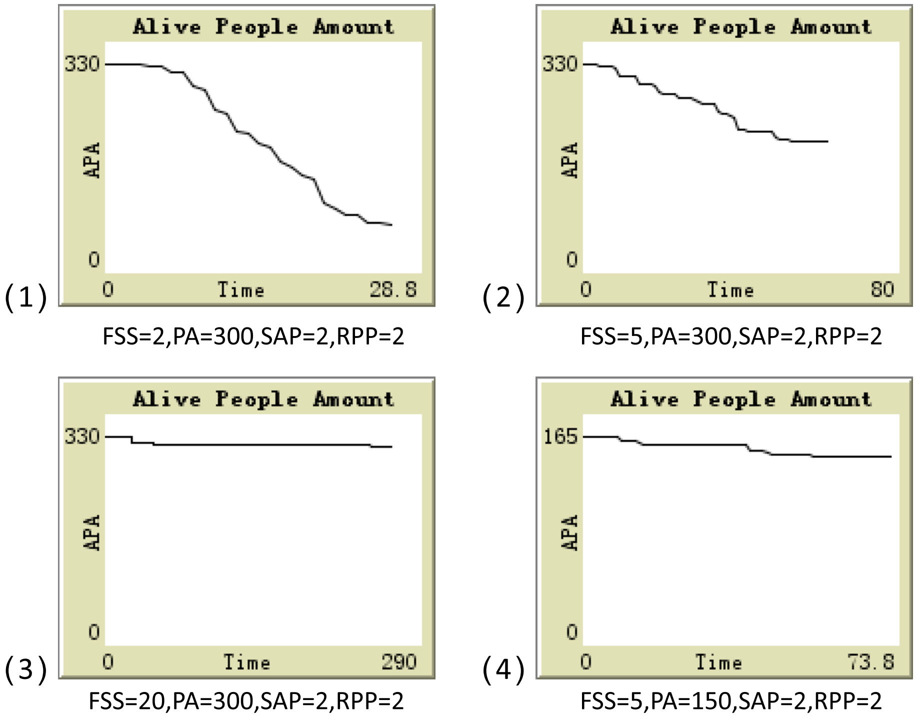
Fig. 2 Simulation operation process

achieved. This is because in such a case everyone escapes from the nearest exit. When all occupants are evenly distributed to exits, the selection of each exit is approximately same. This is the way to minimize congestion and to achieve the best escape survival rate. Meanwhile, the tables also show that the larger the number of occupants is, the smaller the escape survival ratio will be eventually.

In phase 3, the goal is to explore how risk preference ratio and stress ability ratio interactively impact the final escape survival rate (APA). Most settings are the same as those in phase 2. The only difference is that phase 3 adds risk preference proportion (RPP) to the setting list. In three cases showed in Tables 5, 6, and 7, RPP are set as 0.1, 0.5, and 1.0 respectively. Suppose that occupants are familiar with both two formal exits, and that they show the analog value of the escape survival ratio in the group with different individual stress ability. In each case, the simulation runs ten times and generates ten different values of escape survival rate. The final escape survival rate is the arithmetic average of these ten values.

Tables 5, 6, and 7 demonstrate that when alternative exits exist, the finding in phase 2 is still valid. The more individuals with strong stress capacities are in a group, the higher escape survival rate this group has. In addition, when the group risk preference ratio is set as 0.5, the highest escape survival rate is achieved. This is because in this setting the number of risk loving occupants is the same as the number of risk avoiding ones. Risk loving occupants choose alternative exits while risk avoiding ones chooses formal exits. Occupants' selections drive them to different exits and congestions are minimized, so the final escape survival rate rises. This result proves the findings reported

Fig. 3 Some typical simulation results



FSS=2,PA=300,SAP=2,RPP=2

FSS=5,PA=300,SAP=2,RPP=2

FSS=20,PA=300,SAP=2,RPP=2

FSS=5,PA=150,SAP=2,RPP=2

Table 2 The 100 occupants case (all occupants are familiar with four exits)

SAP	0.1	0.5	1.0
APA	78.1	87.1	99.5

Table 3 The 200 occupants case (all occupants are familiar with four exits)

SAP	0.1	0.5	1.0
APA	153.0	174.2	197.5

Table 4 The 300 occupants case (all occupants are familiar with four exits)

SAP	0.1	0.5	1.0
APA	181.4	221.4	271.3

Table 5 The 100 occupants case (all occupants are familiar with two exits)

RPP	SAP		
	0.1	0.5	1.0
0.1	77.2	84.8	88.7
0.5	80.6	87.1	94.8
1.0	79.9	81.8	89.9

Table 6 The 200 occupants case (all occupants are familiar with two exits)

RPP	SAP		
	0.1	0.5	1.0
0.1	106.5	124.5	139.5
0.5	144.8	150.9	156.7
1.0	102.3	112.1	126.7

Table 7 The 300 occupants case (all occupants are familiar with two exits)

RPP	SAP		
	0.1	0.5	1.0
0.1	135.6	135.9	164.7
0.5	164.8	183.7	187.4
1.0	119.2	130.1	145.9

by Abrahamsson and Johansson [1]. When stress capacity ratio is set as 1, and risk preference proportion is set as 0.5, a comparatively high escape survival rate can be achieved. But it is still lower than the rate when all occupants know all formal exits. This is because when risk loving/avoiding occupants with high stress capacities choose a formal/alternative exit that is nearest to them, it is better for them to know all exits. If they do not, the one they choose might not be the nearest one.

7 A framework of E-evacuation system for enterprise workshop fire emergency

Risk management of enterprise workshop fire emergency covers each stage of fire management, namely beforehand, concurrent, and afterwards. The key part is how to prepare, organize, and conduct an orderly evacuation. Information technology plays an important role in evacuation preparation, organization, and implementation. As such, this paper proposes an enterprise workshop fire E-evacuation system

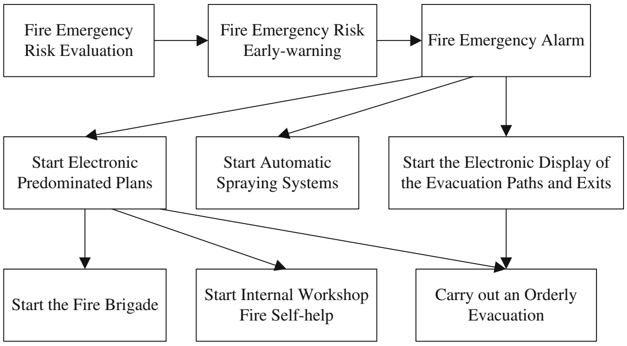


Fig. 4 Framework of E-evacuation system for enterprise workshop fire emergency

shown in Fig. 4. First, enterprises should conduct regular workshop fire risk evaluation and identify potential risks. A workshop fire risk early-warning system should be established. Once a workshop fire potential risk is found, an in-time warning should be available. Second, when a workshop fire occurs, the E-evacuation system should send out a fire alarm immediately, start automatic spraying systems, start electronic contingency plans, and mobilize timely the fire brigade to put out the fire. Meanwhile, workshop occupants should make correct decisions and take proper actions to evacuate. When a fire alarm rings, safe exit signs should be on.

8 Conclusions

Modeling and simulation has many application domains [7, 8, 12, 15, 30, 35]. This paper conducts a multi-agent simulation to explore the relationship between escape survival rate and occupants' risk preferences and stress capacities. The results verify that the escape survival rates of occupants with different risk preferences and stress capacities are significantly different. More specifically, the simulation proves the finding in Kelley and Condry [13] that the smaller the total number of occupants is in a fire, the higher the survival rate is. In addition, the simulation shows that the more individuals with strong stress abilities are in a group, the higher escape survival rate this group has. Moreover, the simulation shows that the more disperse the individuals' risk preferences is in a group, the higher the escape survival rate this group has. These results prove the findings in Abrahamsson and Johansson [1] and Kelley and Condry [13].

The following suggestions can be made from the simulation results to increase escape survival rates during fires. First, make sure that every exit works properly and that occupants are familiar all available exits. Second, provide occupants fire escape training so that their stress abilities can be improved. Third, if alternative exits are available, move risk-loving workers to work close to these exits. Fourth, conduct fire drills and let occupants be familiar with evacuation process. These suggestions can be applied not only to enterprise workshop fire prevention and evacuation, but also to emergency management in other densely populated places.

In addition, enterprises can take the following measures to manage their fire evacuation process: (1) Help employees identify safe exit signs. Safe exit signs usually are in green lights indicating directions in walkways. By following the green lights, employees can find the exits; (2) Maintain smooth communication. When fire occurs, emergency notice should be immediately broadcasted to every corner of the workshop. The start point of fire should be identified immediately and reported to the manager. If a fire is out of workers' control, emergency call should be made right away for outside help. The manager(s) should assign workers immediately to shut down equipment and fight against fire. Meanwhile, the manager(s) should move important documents and data to safe places; (3) Organize workers to escape orderly. When a workshop is on fire, the team leaders should keep calm, count team members, and let them stay where they are. Then each team should find the nearest safe exit sign and follow the directions to escape. Workers on the first floor can jump out of windows directly if the way to exit is blocked. Workers on the second floor need to hang on the windowsill first to minimize the height to ground and then jump. Workers on the third floor and above should close doors and irrigate them so that the fire can be separated. They should use a damp cloth mask to prevent inhalation of toxic gas, and make noises let firefighters know where they are. They also need to lower their bodies close to the floor because air in higher position is not good for breath. Occupants should not consider jumping to the ground because it is easy to get serious hurt or even die. If the condition allows, occupants can help themselves escape. Otherwise, they should remain in a safe place and wait for help. When a fire occurs, elevators should not be taken because elevators are very easy to get stuck due to power outage. Furthermore, elevator shafts often become chimneys during fires. It is very risky and dangerous to use elevators during fires. If there are ladders, occupants can use them and climb to the roof surfaces waiting help there.

Acknowledgments This study was supported by National Natural Science Foundation of China (90924010) and Independent Innovation Research Fund of Wuhan University of Technology (2013-lv-002).

References

1. Abrahamsson M, Johansson H (2006) Risk preferences regarding multiple fatalities and some implications for societal risk decision making—an empirical study. J Risk Res 9(7):703–715

2. Chu G, Sun J (2008) Decision analysis on fire safety design based on evaluating building fire risk to life. Saf Sci 46(7):1125–1136
3. D'Zurilla TJ, Sheedy CF (1991) Relation between social problem-solving ability and subsequent level of psychological stress in college students. J Pers Soc Psychol 61(5):841–846
4. Engelmann JB, Tamir D (2009) Individual differences in risk preference predict neural responses during financial decision-making. Brain Res 1290:28–51
5. Fang S, Xu L, Pei H, Liu Y (2014) An integrated approach to snowmelt flood forecasting in water resource management. IEEE Trans Ind Inform 10(1):548–558
6. Fang S, Xu L, Zhu Y, Ahati J (2014) An integrated system for regional environmental monitoring and management based on internet of things. IEEE Trans Ind Inform. doi:10.1109/TII.2014.2302638
7. Feng S, Xu L (1996) Integrating knowledge-based simulation with aspiration-directed model-based decision support system. Syst Eng Electron 7(2):25–33
8. Gao Q, Xu L, Liang N (2001) Dynamic modeling with an integrated ecological knowledge-based system. Knowl-Based Syst 14(5–6):281–287
9. Gwynne S, Galea ER, Owen M, Lawrence PJ (1999) Escape as a social response. Society of Fire Protection Engineers, Boston
10. Helbing D, Farkas I, Vicsek T (2000) Simulating dynamical features of escape panic. Nature 407(6803):487–490
11. Joo J, Kim N, Wysk RA, Rothrock L, Son YJ, Oh YG, Lee S (2013) Agent-based simulation of affordance-based human behaviors in emergency evacuation. Simul Model Pract Theory 32:99–115
12. Kataev M, Bulysheva L, Emelyanenko A, Emelyanenko V (2013) Enterprise systems in Russia: 1992–2012. Enterp Inf Syst 7(2):169–186
13. Kelley HH, Condry JC Jr (1965) Collective behavior in a simulated panic situation. J Exp Soc Psychol 1(1):20–54
14. Kobasa SC (1979) Stressful life events, personality, and health: an inquiry into hardiness. J Pers Soc Psychol 37(1):1–11
15. Li N, Yi W, Bi Z, Kong H, Gong G (2013) An optimization method for complex product design. Enterp Inf Syst 7(4):470–489
16. Lv Y, Huang GH, Guo L, Li YP, Dai C, Wang XW, Sun W (2013) A scenario-based modeling approach for emergency evacuation management and risk analysis under multiple uncertainties. J Hazard Mater 246:234–244
17. Maddi SR, Khoshaba DM (1994) Hardiness and mental health. J Pers Assess 63(2):265–274
18. Ozbay K, Yazici MA, Iyer S, Li J, Ozguven EE, Carnegie JA (2012) Use of regional transportation planning tool for modeling emergency evacuation. Transp Res Rec J Transp Res Board 2312(1):89–97
19. Pereira LA, Duczmal LH, Cruz FRB (2013) Congested emergency evacuation of a population using a finite automata approach. Saf Sci 51(1):267–272
20. Pires TT (2005) An approach for modeling human cognitive behavior in evacuation models. Fire Saf J 40(2):177–189
21. Proulx G, Sime JD (1991) To prevent 'panic'in an underground emergency: why not tell people the truth. Fire Saf Sci 3:843–852
22. Purser DA, Bensilum M (2001) Quantification of behaviour for engineering design standards and escape time calculations. Saf Sci 38(2):157–182
23. Saloma C, Perez GJ, Tapang G, Lim M, Palmes-Saloma C (2003) Self-organized queuing and scale-free behavior in real escape panic. Proc Natl Acad Sci 100(21):11947–11952
24. Shan S, Wang L, Li L (2012) Modeling of emergency response decision-making process using stochastic Petri net: an e-service perspective. Inf Technol Manag 13(4):363–376
25. Shan S, Wang L, Li L, Chen Y (2012) An emergency response decision support system framework for application in e-government. Inf Technol Manag 13(4):411–427
26. Shields TJ, Boyce KE (2000) A study of evacuation from large retail stores. Fire Saf J 35(1):25–49
27. Sime J (1992) Human behaviour in fire summary report. Central Fire Brigades Advisory Council for England and Wales, London
28. Sime JD (1994) Escape behaviour in fires and evacuations, design against fire: an introduction to fire safety engineering design. Chapman & Hall, London
29. Sun QF, Kong FS, Zhang L, Dang XW (2011) Construction of emergency evacuation information system based on the internet of things. In: Proceedings of 2011 international conference on mechatronic science, electric engineering and computer, Jilin, China, pp 342–345
30. Tan W, Xu W, Yang F, Xu L, Jiang C (2013) A framework for service enterprise workflow simulation with multi-agents cooperation. Enterp Inf Syst 7(4):523–542
31. Taylor SE (1999) Health psychology. McGraw-Hill, New York
32. Tisue S, Wilensky U (2004) NetLogo: design and implementation of a multi-agent modeling environment. In: Proceedings of agent conference on social dynamics and interaction, reflexivity emergence, Chicago, IL, pp 7–9
33. Wang L, Xu L, Bi Z, Xu Y (2014) Data cleaning for RFID and WSN integration. IEEE Trans Ind Inform 10(1):408–418
34. Xie K, Liu J, Chen G, Wang P, Chaudhry S (2012) Group decision-making in an unconventional emergency situation using agile Delphi approach. Inf Technol Manag 13(4):351–361
35. Xu L (1992) Simulating societal systems. IEEE Potentials 11:18–21
36. Xu S, Xu L, Basl J (2012) Introduction: advances in e-business engineering. Inf Technol Manag 13(4):201–204