Simulation of Crowd Response During Emergency Considering People's Rational and Irrational Thinking

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ABSTRACT

Human beings have been facing numerous emergencies which could threaten their property or even their lives in all ages. In order to learn how people respond to the emergencies like earthquakes and fire disasters, a two-stage simulation considering people's rational thinking and irrational thinking was conducted. Results show that people's irrational thinking, like the herd effect, could exaggerate people's behavior of conformity, and it changes the spatial features that stronger herd effect leads to higher cohesion level. It is also worth mentioning that crowd response of condition of smaller population is harder to predict because of its instability, and the response of the very first part of people who make decisions could make great changes to the whole crowd's response. These results could give some enlightenment on the evacuation instruction during emergencies and future research works.

Keywords

Crowd response, evacuation, expected utility theory, herd effect.

INTRODUCTION

Emergencies, like sudden natural hazards, fire disasters, explosions and terrorist attacks, have been one of the major threats for human being's survival in history. By means of effective warnings people could reduce loss to a minimum extent before the scientists find ways to predict them earlier. While the final effectiveness of the warnings does not only depend on the development of science and technology, but also rests with people's rapid and correct responses.

The whole response process mainly includes warning receiving, decision-making and action taking. The warning receiving is a relatively objective process. It is closely related with the warning dissemination process, including source, emitter, channel, receiver and sink according to Shannon and Weaver Model (Shannon, 1949). The decision-making process starts from people receiving the warning information and ends with their making up minds to take actions or decide not to take any action. In emergent cases, like fire disasters, this process decides whether people evacuate or not, when to evacuate, how to evacuate, where to evacuate, and with whom to evacuate. The action taking is a process making the decision made in the last stage come true. It's worth mentioning that these three stages are mutual fusion and integrated that in many cases people also keep receiving new warning or information, making or changing their decisions in the meanwhile when they are taking actions. In this research, the decision-making process is the main point of study.

The behavioral decision theory is one of the applicable method to explain people's decision making in theoretical way. It has been largely applied in financial problems, government decision-making, consumer behaviour, individual choices, emergency response, and many other fields (Prather and Middleton, 2006; O'Hare and Smitheram, 1995; Stahl and Harrell, 1981; Maguire and Albright, 2005; Fischhoff, 2010). The brought up of Expected Utility Theory by Von Neumann and Morgenstern has settled down the development direction of behavioral decision making theory under uncertain conditions (Neumann and Morgenstern, 1944), but it was challenged by several paradoxes because of its assumption of rational actor. Recent years the non-expected utility theory, among which the Prospect Theory is the most popular one, becomes prevailing in related research fields (Tversky, 1979). Until now many researchers are still making efforts to bring up new theories and methods within the framework of expected utility theory to describe people's decision-making process and fix the paradoxes that the expected utility theory could not solve. For example, introducing the uncertain theory to expected utility theory (Yao and Ji, 2014; Chen and Park, 2017); introducing extra parameters to achieve equivalent predictions as cumulative prospect theory (Charles-Cadogan, 2016); and proposing a construction-specific utility framework based on expected utility theory (Alozn and Galadari, 2017).

Some researches attempted to validate these theories by methods of experiments, and results showed that measures based on expected utility model obtained some degree of convergent validity and could be good predictors of actual market behavior (Smidts, 2000). While some doubted that expected utility theory failed to effectively predict people's behaviors and that the prospect theory was more consistent with the experiment results (Friedman, et al., 2014; Baillon and Bleichrodt, 2015). However, different voices were raised that the expected utility theory was revealed to be insignificantly different from other models and could satisfy all of the preferences the other theories could do (Hu, et al., 2012; Pettigrew, 2016). Abellan-Perpinan looked into the consistency of these theories in health area and found that the prospect theory was more consistent with rankings and choices but not not with intertemporal decisions compared with the expected utility theory (Abellan-Perpinan, et al., 2009). As concluded by Ivan Moscati, who reconstructed the trajectory of experimental researches of expected utility theory between 1950 and 1985, the flaws of EUT-based utility measurement do not undermine the utility measurement in general (Moscati, 2016).

Compared with the behavioral decision making theory which applies to individual decision making, crowd decision making seems more complex and unpredictable. Crowd behavior is one of the most popular research topics both in sociology and psychology fields, and by now there has been a number of representative findings that promote the researches' development. An important research about crowd behavior is Sherif's experiment of autokinetic phenomenon, demonstrating that individuals are easy to get affected by other people's suggestive influence (Sherif, 1936). Another typical research is Asch's conformity experiment revealing that social pressure from the majority of the group could exert influence on people's conformation behavior (Asch and Solomon, 1956). After that, researches related to crowd conformity behavior sprang up, especially in the field of financial behavior researches. A mass of researches investigated the stock markets around the world and proved the existence of herding behaviors, including the U.S.A., Japan, Germany, China,Turkish, and some other countries (Demirer, et al., 2014; Ashiya and Doi, 1999; Cakan and Balagyozyan, 2014; Babalos, et al., 2015; Yao, et al., 2014; Cajueiro and Tabak, 2009; Kremer and Nautz, 2013).

Researches specific to emergent occasions are much less in quantity compared with the researches of crowd behavior defined in common occasions,. There are several prominent theories should be mentioned, including Emergent Norm Theory, Inter-group perspective brought up by Reicher and Potter (Reicher and Potter, 1985), Model of Disorder brought up by Waddington (Waddington, 2010), Social Identity Theory brought up by Turner, Oakes, Haslam and McGarty (Turner et al., 1994), and Elaborated Social Identity Theory brought up by Reicher and Drury (Drury and Reicher, 1999). These theories provided frameworks for related researches to look further into crowd behaviors during emergencies. Empirical experiments also proved the existence of herding behavior during emergencies (Altshuler, et al., 2005; Wei, et al., 2014).

Recent researches also started to make efforts to discover the secrets hidden under people's herd behaviors. It was found that people's herd behavior depends on both environmental and personal factors, like the knowledge about the alternatives options, and that only under condition of certain level of uncertainty would the herd effect occur (Lovreglio, et al., 2016). Another perspective insists that the herd behavior does not applicable to all emergencies, for example, people prefer not to follow the majority's escape route under crowded and no choice uncertainty conditions (Haghani and Sarvi, 2017). Some found that the herd behavior occurred when the individual interactions were strong (Chang, 2014). Based on these findings, researchers tried to establish qualitative and quantitative models to explain and analyze the herd behavior, like the sequential decision model (Banerjee, 1992; Morone, 2012), informational herding model (Cipriani and Guarino, 2014), and an asymmetric information and Baysian learning model (Hott, 2009).

The researches mentioned above are mostly qualitative and empirical studies. Based on these theories, many researchers have built up various quantitative models to simulate people's behaviour during emergencies, mostly focusing on people's evacuation process, such as pedestrian behaviour, evacuation time, jamming phenomenon, bottleneck effect and so on. Some prominent researches include Helbing's research integrating panic behaviour and quantitative theories published in Nature (Helbing et al., 2002), Burstedde's simulation of pedestrian dynamics using a two-dimensional cellular automaton (Burstedde et al., 2001), Kirchner's simulation of pedestrian dynamics using a bionics-inspired cellular automaton model (Kirchner and Schadschneider, 2002), and some other related researches (Luo et al., 2008; Zaharia, 2009; Wu, 2014; Wagner, 2014).

In summary, to describe people's individual decision-making under rational thinking, the expected utility theory could be a relatively effective method in spite of its defects in explaining some paradoxes. On the other hand, the influence of surrounding people was proved to be existing, which makes the crowd to show a tendency of irrational herding behavior, and eventually make great differences on people's evacuation results. However, the quantitative researches of people's response during emergency are not many, among which mostly focusing on the evacuation process, but not much on the decision-making process before people take actions of evacuation. In this research a two-stage simulation was conducted integrating people's rational thinking of individual risk perception based on expected utility theory and irrational thinking affected by herd effect using method of cellular automaton in order to study people's possible response under different conditions, and some meaningful findings were put forward.

MODEL AND SIMULATION DESIGN

From the angle of complex adaptive system, cellular automaton (CA) could simulate the emergent feature of systems by constructing cellulars at the microcosm level and designing rules for the cellulars to interact. Now it has been widely used to simulate the social system, especially people's evacuation processes during emergencies. A cellular automaton model could be defined by a quadruple form, donated by $CA = (S, X, V, f)$, where S is cellular space, X for cellular states, V for cellular neighborhood, and *f* for transition rules of cellular states. It is suitable for simulating people's decision-making process because of the following reasons:

1. The limited cellular space in CA model is consistent with the indoor environment where the decision-making processes usually happen in real world.

2. Cellular states could reflect each individuals properties during decision-making, like decision intention, decided or not and evacuate or not.

3. Cellular neighborhood explains who exert an influence on the cellular's decision and the transition rule explains how they make the influence happen.

While the normal cellular automaton could only simulate homogeneous properties and distribution that all cellulars obey the same rule and are located orderly, which do not fit in the real social system. By integrating the method of Agent-based Model (ABM) it could well solved these problems for its feature of heterogeneity. So here we use the CA settings to simulate people's decision-making but use the ABM method to realize the simulation processes with heterogeneity.

Assume that there are people amount of N regularly located in an indoor environment, like a classroom, an office or a concert hall. The whole simulation includes two stages, corresponding to people's decision intention and interaction processes.

1. Decision intention (rational process).

Once the emergency alarm rings, for example, the fire alarm or an earthquake early warning, individuals first form their decision intention, to make it simple, of evacuate or not, and basically it is a relatively rational process. In financial researches, the expected utility theory was widely used to describe how people make choices based on potential gains and losses, which could also be utilized to calculate people's decision-making intention under emergency conditions. The following table describes the payoff matrix of each individual choosing to evacuate and not evacuate under the circumstances of true alarm and false alarm.

Table 1. Payoff Matrix of Evacuation Intention

Payoff	True	False
Evacuate	a_i	b_i
Not evacuate	c_i	d_i

According to the expected utility theory, the expected utility is given by

$$U = p_1 u(x_1) + p_2 u(x_2) \tag{1}$$

Let $p_i (0 \le p_i \le 1)$ be the perceived probability of emergency happening of individual *i*. So the value function of each individual *i* is given by

$$U_i(evacuate) = p_i a_i + (1-p_i) b_i \tag{2}$$

$$U_i(not-evacuate) = p_i c_i + (1-p_i) d_i \tag{3}$$

Assume that the evacuation intention was entirely decided by the expected utility. Let

$$U_i = U_i(evacuate) - U_i(not-evacuate) \tag{4}$$

then

$$y_i = \begin{cases} 1(evacuate) & U_i > 0 \\ 0(not-evacute) & U_i \le 0 \end{cases} \tag{5}$$

2. Interaction (irrational process).

In order to simulate people's herd behavior, in other words, imitating the majority's behavior, which is an irrational process, the assumption that people's final decision could be affected by the decisions of other people was inserted. Let V_i be the neighbourhood of individual i. We assume that individual *i* might get affected by the proportion of people decided to evacuate in the range of V_i . Let $q_i (0 \le q_i \le 1)$ be the potential of being influenced by others, λ_i be the proportion of people decided to evacuate in the neighbourhood range of V_i .

If individual *i* is not influenced by others, the probability of evacuating is totally decided by the individual's evacuate intention. If individual *i* is totally irrational and influenced by others, the probability of evacuating is decided by the herd effect.

$$E(q=0) = u \tag{6}$$

$$E(q=1) = \lambda \tag{7}$$

So the probability of individual *i* to decide to evacuate is given by

$$E = (1-q)u + q\lambda \tag{8}$$

The above model takes people's expected utility as the reference point of herd effect. If individual *i*'s evacuation rate is larger than his/her value function, the probability of evacuating will increase, and vice versa. While another idea is to take the majority's decision as the reference point, in other words, if the majority in the range of V_i choose to evacuate, individual *i*'s evacuate rate would go up, indicating that

$$E = u + cq(\lambda - 0.5) \tag{9}$$

where *c* is a constant decided by *u*.

For the condition that $\lambda - 0.5 \ge 0$, a boundary condition is that

$$E = 1 \text{, when } q = 1, \lambda = 1 . \tag{10}$$

So

$$c = 2(1-u) \text{, } E = u + 2q(1-u)(\lambda - 0.5) . \tag{11}$$

For the condition that $\lambda - 0.5 < 0$, a boundary condition is that

$$E = 0 \text{, when } q = 1, \lambda = 0 . \tag{12}$$

So

$$c = 2u \text{, } E = u + 2uq(\lambda - 0.5) . \tag{13}$$

So when the reference point is the majority's decision, the calculation function is:

$$E = \begin{cases} u + 2q(1-u)(\lambda - 0.5) & \lambda - 0.5 \geq 0 \\ u + 2uq(\lambda - 0.5) & \lambda - 0.5 < 0 \end{cases} \tag{14}$$

An important factor that could make change to people's decision is their decision time. Some people make decisions very quickly that they do not need to observe others decisions to make decisions, while some might need to refer to all other people's decisions to make their own ones. So we assume that people's decision time satisfies a normal distribution $T \sim N(t, \sigma^2)$, that is,

$$f(t) = \frac{1}{\sqrt{2\pi}\sigma} \exp(-\frac{(t - t_0)^2}{2\sigma^2}) \tag{15}$$

where t_0 is the mean observing time for all individuals.

SIMULATION RESULTS

The simulation was conducted on Netlogo 5.3.1. In order to simplify the simulation, the following variables were assumed to be normally distributed:

Perceived reliability of warning: $p \sim N(p_0, \sigma^2)$.

Probability of being influenced by others: $q \sim N(q_0, \sigma^2)$.

Considering that simulation of larger population could narrow the simulation errors with little influence on the simulation results, the total population was set to be ten thousand for each simulation. The value of a_i, b_i, c_i and d_i in Table 1 were set to be non-dimensional numbers ranged from 0 to 10 with initial value of 5, representing the neutral attitude towards all the losses. According to Equation (2), (3) and (4), the effective variables that changes the utility could be simplified to (a-c) and (b-d). Further simplification is conducted to set (b-d) equals zero and (a-c) varies from -10 to 10 when concerning the changes of payoff evaluation.

In order to study the time-dependent characteristics of evacuating decision-making, the variables were set to be a set of values which could roughly reflect the tendency of evacuation rate curve, and changes of these values would not make difference on the shape of the curve (Table 2).

It is easy to find that the frequency curve for people who decided to evacuate and not to evacuate goes up slowly in the beginning, and starts to explosively grow with time goes, and finally reaches to the maximum with slower and slower speed. The burst of decided people could be due to the normally distributed decision time, or the herd effect of imitating others behavior.

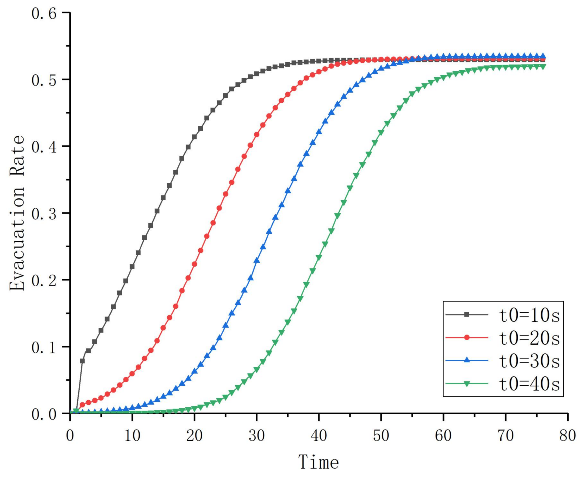

Figure 1. Evacuation Rate of Different Decision time

Firstly, the influence of decision time is evaluated and people's mean decision time (t_0 in Equation (15)) is set to be 10 seconds to 40 seconds. It is obvious that the mean decision time of the crowd does not make a difference on the final evacuation rate or the rising tend except the equidistant x-offest of the curves. A small detail could be found in the graph that at the very first time people make evacuation decisions in the condition of very short decision time, the curve is not smooth but connected by an inflection point. This phenomenon could be attribute to the large gap between the actual evacuation population at the first point and the supposed evacuation population with normally distributed decision time.

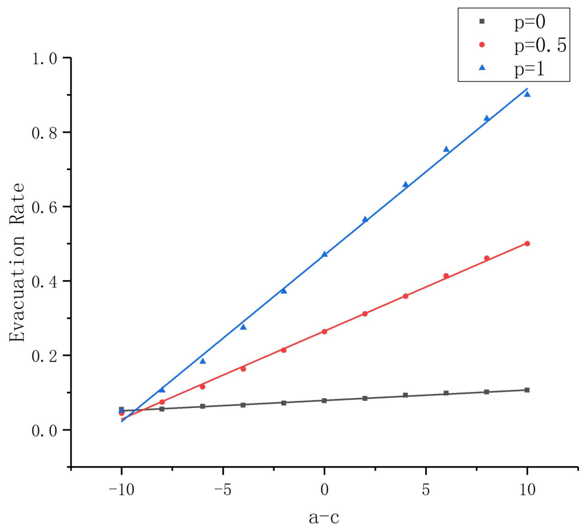

Figure 2. Evacuation Rate of Different Warning Reliability

It is intelligible that evacuation rate was a linear function of utility if we set the conformity level to be zero to minimize the influence of herd effect. While this linear tendency could be affected by the warning information that the evacuation rate of different warning reliability (p_i in Equation (2) and (3)) is simulated. As shown in Figure 2, with more reliable warning, more people would choose to evacuate, which is accorded to our assumption and previous researches on warning reliability (Meyer and Joachim, 2001; Roy et al., 2015).

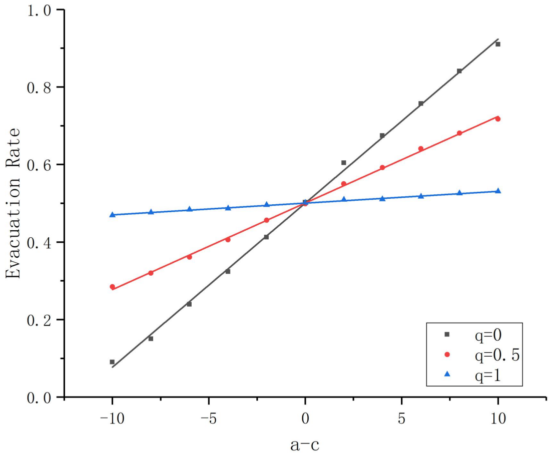

Figure 3. Evacuation Rate of Different Conformity Level (utility as reference point)

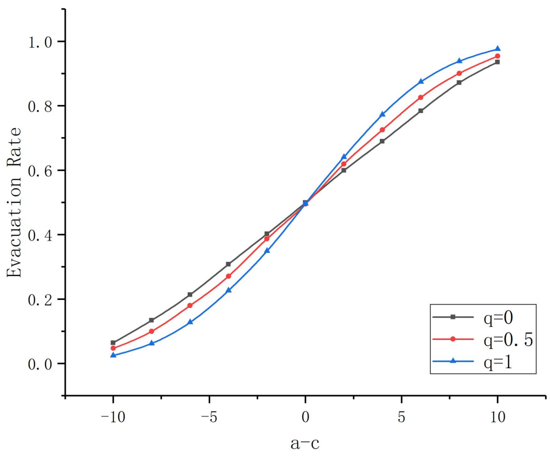

Figure 4. Evacuation Rate of Different Conformity Level (0.5 as reference point)

Besides, the herd behavior could also change people's evacuation decision as Figure 3 and Figure 4 show. If we employ the model of setting individuals' value function as comparison point (Equation (8)), it is found that when the value of utility is larger than zero, the stronger the herd effect is, the lower the evacuation rate could be. On the contrary, when the utility is lower than zero, the stronger the herd effect is, the higher the evacuation rate is. Though this result could be explained by mathematical analysis of Equation (8), it is not corresponding to our common sense. While if we employ the other model which takes the majority's decision as reference point (Equation 14), more reasonable results are found. Contrary to the result of the other model, when people's value function is larger than zero, the stronger the herd effect is, the higher the evacuation rate is. This result is consistent with both our common sense and previous findings (Helbing et al., 2000; Herbst and Mas, 2015). And an information acquired from the figure is that this kind of amplification effect is not same for each utility. For example, it reaches the most obvious point when the expected utility function equals 5 and -5, and least obvious at the zero point and the two ends of the utility function due to the limitation of the maximum evacuation rate.

The comparison of patterns of the crowd's final decision is more visualized. When there is no herd effect, the pattern of decision-making is quite dispersive because people make their decisions only based on their utility, which is totally not affected by others decisions. While for the strong herd effect condition, the pattern of decision-making changes to a relatively conterminous mode, because people do not make their decisions based on their heterogeneous utility but their neighbors' decision.

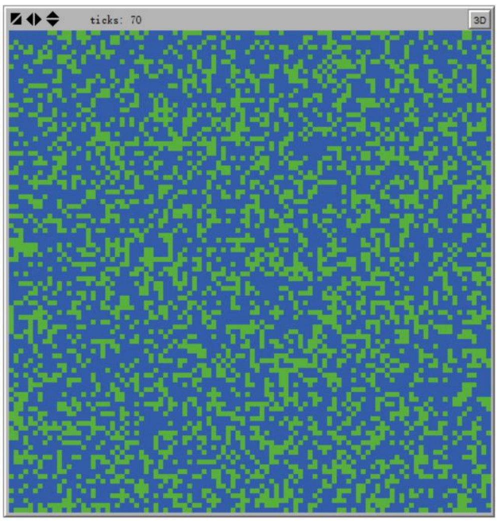

Figure 5. Spatial Pattern of Weak Conformity Level

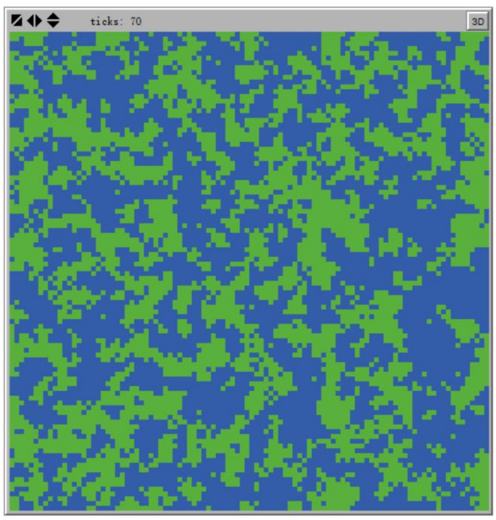

Figure 6. Spatial Pattern of Strong Conformity Level

Another finding is that if we change the neighborhood selection strategy from Moore neighborhood to the global viewing angle, which means each individual could observe all people in the same space and imitate their behaviour, the decision pattern gets dispersal again and it doesn't change with the herd effect getting stronger. While this scenario is not realistic because people do not have the ability to observe all ten thousand neighbors in the same space. In most cases, people could only observe neighbors around them within their vision.

In order to evaluate crowd's dispersivity level, the definition of centrality and centralization potential in the field of social network are employed here (Freeman, 1979). Centrality measures the degree to which one node in a network is connected to all other nodes, and the centralization measures the concentrative degree of the whole network, which is decided by the centrality of all nodes. It's defined by

$$C = \frac{\sum(C_{\max} - C_i)}{\max[\sum(C_{\max} - C_i)]}, \tag{16}$$

where C_i represents the centrality of individual i and $C_{\max}$ represents the maximum centrality of all people. According to the simulation result, the centralization mode is quite different for different neighborhood selection strategies. The calculation result shows that the centralization does not change according to people's conformity level when all other agents are set to be agent i's neighbors. But things change when the neighborhood is set to be the Moore neighbors that the centralization level is negatively linear with the conformity level, in other words, higher conformity level leads to higher cohesion.

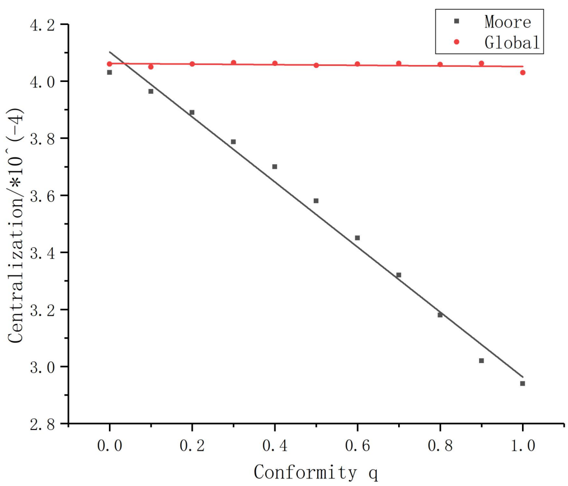

Figure 7. Evacuation Rate of Different Neighborhood

Above results are obtained under the condition of ten thousand population in a certain space, while it is not a common scenario to have such a large event held in a site able to accommodate ten thousand people. Theoretically, the average evacuation rate of simulations repeat times without number should be the same no matter how many numbers of people, but the result could change if we only repeat limited times. If we take the situation of complete herd effect as an example, theoretically the average evacuation rate should be around 0.5. From the simulation result, we can see that with the population going up, the average evacuation rate gets closer to to theoretical value, and the stability gets higher for the shorter length of variation range. While for smaller population cases, especially for the 25 people group, the median and average evacuation rate was almost 10% away from the theoretical value. And for the the extreme cases, the evacuate rate could be lower than 0.3 and higher than 0.6. This kind of case variation is due to the small sample size of each case. In many scenarios, there are only tens of people or even less than 10 people in a room, like classrooms and offices, so people's decision under emergency condition could have quite different results.

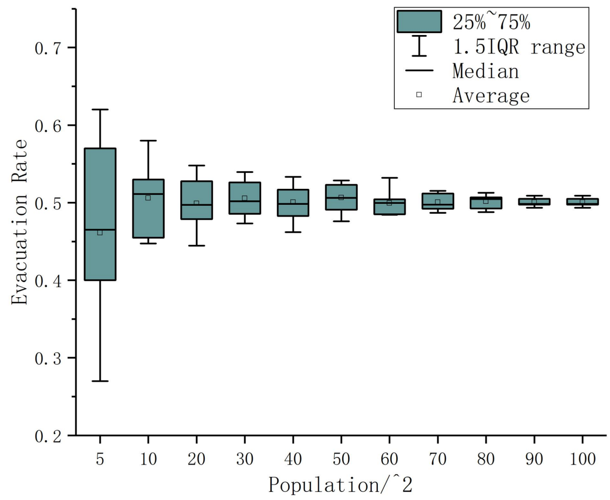

Figure 8. Evacuation Rate of Different Population

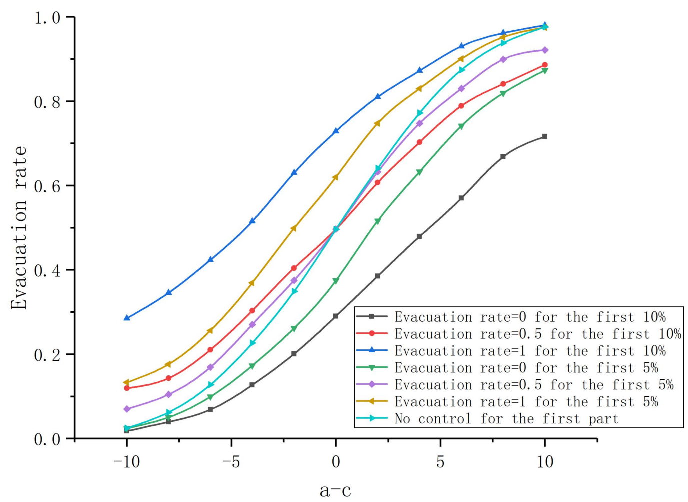

Figure 9. Evacuation Rate When Controlling the First 5% People and the First 10% People

Based on Equation (14) and the previous researches on herd effect, neighbors who first make decisions could have great impact for the others. In this simulation, the influence of the first 5% and 10% parts of neighbors who make decisions are studied. According to the simulation result, higher evacuation rate of neighbors who make decision first could effectively raise individuals' final evacuation rate. For example, when people is irresolute on whether to evacuate or not (utility=0), if all of the first 5% neighbors make decisions to evacuate, the total evacuation rate could raise by 20%, and by 40% for the condition of the first 10% neighbors decide to evacuate. Similar results could be found when the first part of neighbors decide not to evacuate. And this effect is particularly significant when individuals' first evacuation intention is quite low that the total evacuation rate could raise over 5 times and even 10 times. This remarkable effect is consistent with Dyer's empirical experiment of leadership effect in crowd decision-making (Dyer et al., 2008) and could be taken advantages in evacuation strategies during emergencies.

The variable settings of the above simulation were presented in Table 2.

Table 2. Variable Settings in Each Simulation

No.	Independent Variable	Corresponding Figure	a-c	b-d	warning reliability p	Conformity Level q
1	Decision time	Figure 1	4	-4	0.6	0.5
2	Warning reliability	Figure 2	-10~10	0	0, 0.5, 1	0

3	Conformity level	Figure 3 and 4	-10~10	0	1	0, 0.5, 1
4	Neighborhood	Figure 7	0	0	1	0~1
5	Population	Figure 8	0	0	0.5	0.5
6	Controlled evacuation rate for the first 5% and 10% people	Figure 9	-10~10	0	1	1

DISCUSSION

According to the simulation results, the shapes of the evacuation decision-making curve do not change when the decision-making mean time changes. But the changes in the position of coordinate axes show the importance of the decision-making timing. For example, the lead time of a sever earthquake usually lies between seconds to tens of seconds. For a 20-second earthquake early warning, people need to make decisions of evacuate or not in 20 seconds, so it would be quite dangerous for crowds whose decision time was normally distributed with average of 20 seconds, 30 seconds or even more. Now that the great differences of the final results in limited time with different decision time have emerged, some other questions about the decision timing should be studied. What decides people's decision-making time? Is it decided by personal characteristics, surroundings, warning information or other people's behavior? How to shorten people's decision-making time while keeping people to be rational under emergent condition? These questions could be looked into by experiments or real cases analysis and the answers to these questions could be of great importance on decreasing emergency losses.

In this simulation, we assume that the expected utility is decided by the alarm's reliability and people's payoff matrix. It is easy to understand that when the utility is over zero, people's evacuation rate goes up with the alarm reliability getting higher. So it is of importance to improve the warning's reliability but it is still unknown that how to evaluate the alarm's reliability and how to match the public's perceived reliability and the authority's technical reliability.

It is also feasible to raise people's evacuation rate by changing their payoff matrix, in other words, increasing people's benefits of evacuating (decreasing people's losses of evacuating) or decreasing people's benefits of not evacuating (decreasing people's losses of not evacuating). For the first circumstance, measures of improving evacuating convenience and increasing compensation for emergency losses could be conducted, for example, designing and constructing more convenient escape ways and increasing the compensation rate for people who take positive actions to reduce losses. For the second circumstance, the government and related departments could increase people's subjective evaluation of emergency losses by improving emergency education to help people realize the severe consequence it could result in. Apart from understanding how to improve people's response during emergencies, researches should also study further on the formation of people's payoff evaluation. For example, what kinds of factors result in people's differences of payoff evaluation? Is there any way to change people's payoff matrix, and further to change people's decision-making under emergent occasions?

As the results show in the last section, people's final decisions could be largely influenced by the first part of people who make decisions because of herd effect. Usually people are criticizing the herd effect because herd effect is a kind of expression of irrational thinking, but sometimes we can also utilize this irrational thinking to reach a better consequence. There is a great probability that people might not make an objective decision by their rational thinking, resulting in the gap between their real decision and the authorities' expected decision. Under this circumstance, if people who make decisions first could make correct decisions, and then the others, who do not have a reasonable evaluation of evacuation payoff, could just imitate others correct behavior with less considering the incorrect analysis of themselves, improving the final results for the whole. While opposite things could also happen that people who could make correct decisions are influenced by people who make incorrect decisions, worsening the emergency consequence. So the authority could find ways to educate or induce people who make decisions most quickly or other people who could largely insert influences on others to make correct decisions to narrow the gap between expected response and real response. So now the problem is detailed to be the problem of people who make their decisions quickest: What kinds of factors decide people's decision time and who are probably the one who make decisions earliest? Apart from the timing of making decisions, what else could be the influencing factors for the crowd, such as the social relationship? And ultimately how can we utilize people's psychology of herd effect to improve people's emergency behavior? In a word, there are still too many ignorant questions to be dug out.

Another important factor in this simulation is the neighborhood selection strategy. From our simulation result, the smaller neighborhood range could make crowd's cohesion level higher. Though it seems not useful for the final evacuation decision rate, it could eventually affect people's evacuation process. Crowd of higher cohesion level are more likely to create congestion in the evacuation route and crowd of lower cohesion are more likely to avoid congestion because their dispersive decision pattern. While when the population is large or part of the room space is shielded, it is not possible for human eyes to observe all people in the same space because of the limited vision field or their personal psychological condition. So here comes the questions: How large should people's neighborhood range be? Is it only limited to people's vision field? Do all people usually set their observation range fixed or do they change according to people with different personal characteristics?

CONCLUSION

The simulation provides a method to simulate crowd's decision-making condition taking people's rational evaluation and irrational thinking into consideration respectively in two stages. The results show that the reliability of the alarms and the herd effect could have great influences on people's decision-making during emergencies, and the control of part of people who make decisions first could help the manage departments to command the emergency condition to an expected way. These results support the findings of previous researches on warning reliability, herd effect and leadership effect.

Based on the above findings, several measures reducing the emergency loss are put forward, including reducing people's decision time, improving warning's reliability, improving evacuating convenience and compensation for emergency losses, improving emergency education to help people realize the severe consequence it could result in, finding ways to educate or induce people who make decisions most quickly or other people who could largely insert influences on others to make correct decisions.

However many questions related to people's decision time, warning reliability and conformity behavior are still unknown in this field. The research questions mentioned in discussion section are all deserve to look deeper into and could help people learn more on crowd behaviors during emergencies, and reduce people's property loss and possible casualty in the end.

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