Applied Mathematics and Computation 320 (2018) 485–494

Contents lists available at ScienceDirect

Applied Mathematics and Computation

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

Emergence of cooperation during an emergency evacuation

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ARTICLE INFO

Keywords:
Cooperative behaviors
Crowd evacuation
Cellular automata
Escape aspiration
Complex system

ABSTRACT

Understanding how crowds behave in an emergency has long been held to be necessary to emergency response and management. Competition due to mass panic is often assumed to be a natural response during emergencies, which is in contrast with the current psychological research that evacuees rarely demonstrate competitive behaviors, but do exhibit cooperative behaviors. In this work cooperative behaviors and evacuation efficiency has been examined in detail by using a cellular automata evacuation model from a game-theoretical perspective. Simulation results show that the self-regarding evacuees are able to be cooperative to each other when faced with an emergency. It is found that during an emergency evacuation high levels of escape aspiration promote cooperation among evacuees while in non-emergency situations they inhibit cooperative behaviors, and heterogeneous learning rates for different strategies can lead to various levels of cooperation. This work provides a new insight into crowd behaviors in an emergency evacuation.

1. Introduction

Hundreds of thousands of people are gathered up in mass events such as Olympic Games, world expositions, and other popular entertainment events; in addition, a great number of people also assemble at traffic hubs including subway, railway and air stations during rush hours. In these cases, there are potential safety issues. If a danger such as a fire accident, natural disasters or other possible terrorist attacks occur, evacuee's escaping behaviors are likely to result in crowd crushes or stampedes [1]. Therefore an accurate understanding on evacuation behaviors during emergencies is valuable for it can provide new insights in managing and controlling crowd evacuation as well as the design of safety facilities.

Great interests from various scientific communities such as physics [2–5], applied mathematics [6–8], pedestrian traffic [9,10], computer simulation [11,12] and other applied engineering [13–15] are drawn up to the topic of evacuation and pedestrian dynamics [16]. Since Helbing et al. [2] proposed the well-known social force model to simulate escape panic of crowd, the concept of mass panic has been influential in crowd modeling [17]. The panic theory involves a breakdown of social order and ruthless competition for exits, which is in sharp contrast with the social and psychological observations that competitive and disorderly behavior are extremely rare, with cooperation being commonplace [17,18]. The mass panic theory has been largely rejected in academic psychology and sociology, and other theories and approaches such as normative approach [18], affiliation model [19] and social identity approach [17] have been put forward to explain such sociality. Especially the social identity theory is capable of interpreting the most significant recently observed behavior in emergency crowds: cooperation among strangers, which the other approaches cannot address. Through interview study [20,21] and human experiments by virtual reality paradigm [22] it has been found that collective identity in an emergency crowd

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https://doi.org/10.1016/j.amc.2017.10.011
0096-3003/

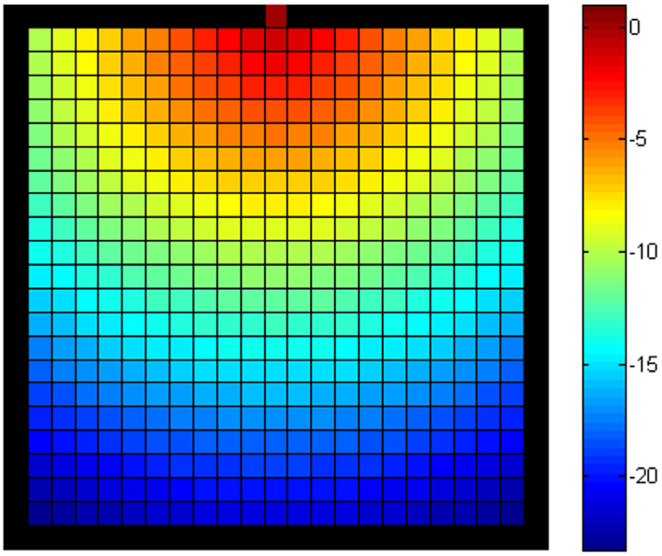

Fig. 1. Static floor field of the room in simulation. The value of static floor field at the exit is zero. The value of static floor field at other location is non-positive and its absolute value is equal to the Euclidean distance from the position to the exit.

enhances expressions of solidarity and reduces panic behavior, which provides an explanation to the emergence of cooperation in emergency conditions from the perspective of crowd psychology. The researchers need to bridge the gap from crowd psychology to crowd evacuation models by making computational models consistent with the recent psychological findings. Yet to our best knowledge there is little research work reproducing the observed phenomenon that people are able to keep cooperative behaviors spontaneously during an emergency evacuation.

This work is aimed at providing such a model to exhibit how cooperation emerges among self-regarding individuals during emergencies from a game-theoretical perspective. It is well-known that game-theoretical approach is a good tool to study cooperation between self-regarding individuals [23–31]. Zheng and Cheng [32] introduced a framework of evolutionary game theory combining cellular automata evacuation model to study the evacuation process. Shi and Wang [33] proposed a snowdrift game theory model for the pedestrian evacuation process in a single room and found that moderate value of cost-to-benefit ratio leading to the shortest escape time. Heliövaara et al. [34] proposed a spatial game theoretic model with estimated evacuation time being payoff function to study effect of pedestrian patient and impatient behaviors on evacuation process in situations of exit congestion by social force model. Bouzat and Kuperman [35] analyzed the pedestrian evacuation of a room with a single door considering a lattice gas model with the addition of pedestrian behaviors determined by the rules and payoffs in various types of game and found that cooperators can take advantage from mutual cooperation under certain conditions. Most of the previous work is of exploratory research in the pedestrian dynamics, rarely involving crowds with inclusion of evolutionary strategies during an emergency evacuation.

In this work, the evolutionary game-theoretic approach is applied in an evacuation model based on cellular automata to investigate the emergence of cooperation in emergency evacuation and the relationship between escape aspiration and frequency of cooperation during an evacuation.

2. Model

A cellular automata (CA) model is used to describe the evacuation dynamics. CA can sufficiently represent phenomena of arbitrary complexity in the real-world and subsequently reveal the evolution of complex systems [36]. It is a quite useful tool in studying dynamical and nonequilibrium systems and its applications exist in many areas of science [37,38]. In this work, to describe the evacuees' movement, a CA model with von Neumann neighborhood is used. An evacuee has four directions (up, down, left, and right) to move, and the rules of a person's motion are determined by static floor field $S_{(i,j)}$ [3]. As shown in Fig. 1, the static floor field can be calculated according to distance from the exit measured by Euclidean metric. The dynamic floor field is neglected because its effect has little impact on a single-exit case [39]. The transition probability of person's movements can be expressed as follows:

$$p_{(i,j)} = \frac{\exp(S_{(i,j)}/k_s)}{\sum\limits_{(i,j)\in\Omega} \exp(S_{(i,j)}/k_s)}, \tag{1}$$

where Ω denotes the position set of the evacuee's next accessible position, and k_s, as noise, reflects the evacuee's sense of distance from the exit.