Chapter 22
Modelling Pedestrian Social Group Passing Strategy with Expression-Matrix and Social Force

Long Liu, Yuan Zhao, and Xiaolei Zou

Abstract Our experiments and studies in recent years have shown that the complex pedestrian social group has a hierarchical structure. Small pedestrian groups of 2–3 people are simple groups with stable and straightforward formations. The simple groups are also cellular units that act as subgroups and constitute a more extensive complex social pedestrian group. The complex social pedestrian group has multiple patterns, movement and formation change. In this paper, an Expression-Matrix method is used to coordinate the hierarchical relations of the heterogeneous group and the social relations among subgroup members, and to generate global and local strategies for formation changes of complex pedestrian groups. And an extended social force model is proposed to control the dynamics of group members and forms a stable group formation by adding a set of inner subgroup relationship force and a set of inter subgroup relationship force. Finally, trajectories in the bottleneck scene are compared with the result of the model, which shows the model could accurately describe some of the adoption strategies of complex pedestrian groups.

22.1 Introduction

At present, the research field of pedestrian flow mainly focuses on the characteristics and trajectory analysis in a variety of scenarios based on the single-person model. However, considering that the amount of pedestrian groups in the pedestrian flow is not in the minority [1, 2], and group members have potential impact on the strategy and trajectory of the group in some scenes [3], the primary research and analysis of

L. Liu · X. Zou (✉)
Tongji University, 4800# Cao'an Road, Shanghai, China
e-mail: zouxiaolei@tongji.edu.cn

L. Liu
e-mail: liul0121@tongji.edu.cn

Y. Zhao (✉)
Shanghai Shentong Metro Group Co., 909# Guilin Road, Shanghai, China
e-mail: jituanguizhang@126.com

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groups behavior in pedestrian flow is essential. The behavior of pedestrians in various scenarios can be interpreted as the individual's response to the external environment. How to define different social attributions, distinguish and accurately describe the behavior of pedestrians under the influence of others in a complex social group are the key objects of this study.

22.2 Methods

In order to give a more accurately description of the location of the pedestrians in the complex group and the structure of the entire group, an Expression-Matrix method is used to record the morphological changes of the pedestrian group structure and relative location. On the basis of social force, the study distinguished different members of different subgroups in one group and figure out their different impact on every single pedestrian according to different social relationships.

22.2.1 Expression-Matrix

Expression-Matrix is a kind of symbolic representation of the group structure and positional statistics based on experimental data. By using Expression-Matrix, this method can express the pedestrian group structure more simply and understandably, and use matrix probability to describe the possibility of pedestrians in the group, which means the probability of distribution of locations. In this method Expression-Matrix, at the level of the individual pedestrian, the pedestrian's heading direction is the Y-axis, and the pedestrian position is arranged from left to right along the X-axis. The distance between the pedestrians determines the positional expression symbol of the pedestrian. On the X-axis, the distance is judged mainly based on the shoulder width of the pedestrian, and different races may affect this value. In the Y-axis, the step distance is mainly used as a key reference for judging the position. This method uses the operands such as "|", " + ", "−", "/", "\" to indicate the relative position of the pedestrian. The rules for "|", " + ", "−", "/" and "\" are detailed in [5]. The matrix is defined as a set of cells that covers all of the group members with side lengths of the standard distance for X-axis and Y-axis. A probability is assigned for each cell to describe the location distribution possibility of group members.

Besides, based on experimental observation data [4], the probability of location distribution of pedestrians in different group sizes is also obtained. Based on Expression-Matrix, Huang [5] proposed the basic pedestrian group composition structure and its symbolic expression. Based on Expression-Matrix, this study selected a five-person group with two cellular groups as the research object and used the extended social force model to simulate the travel strategy of the five-person group.

22.2.2 Extended Social Force Model

The social force model established by Helbing is based on Newton's second law of motion. It is believed that individuals in the crowd are single particles that satisfy Newton's law, and each individual is also affected by the interaction of physical and psychological internal and external factors. These factors are expressed in a forceful manner.

Pedestrian movement meets the basic formula

$$\frac{\mathrm{d}\overrightarrow{v}_a}{\mathrm{d}t} = \overrightarrow{f_\alpha}(t) + \overrightarrow{\xi_\alpha}(t) \tag{22.1}$$

where $\frac{\mathrm{d}\overrightarrow{v}_a}{\mathrm{d}t}$ means pedestrian acceleration, $\overrightarrow{f_\alpha}(t)$ is the synergy of the social forces that the pedestrians are subjected to, $\overrightarrow{\xi_\alpha}(t)$ represents the individual random error term for pedestrian α.

Representatively, for the combined force of the social forces of pedestrians, Helbing proposed that the resultant force $\overrightarrow{f_\alpha}$ can be expressed by the following formula

$$\overrightarrow{f_\alpha} = \overrightarrow{f_\alpha}^0 + \overrightarrow{f_\alpha}^{wall} + \sum_\beta \overrightarrow{f_{\alpha\beta}} \tag{22.2}$$

where $\overrightarrow{f_\alpha}^0$ is the self-driving force of the pedestrian α, $\overrightarrow{f_\alpha}^{wall}$ is the repulsive force between the pedestrian α and the wall, $\sum_\beta \overrightarrow{f_{\alpha\beta}}$ is the force of other pedestrians on the pedestrian α.

This is the result of a single pedestrian as a travel unit. When considering pedestrians traveling in groups, the relationship between pedestrians is not only exclusive but also the attractiveness of distances used to meet communication needs. Based on Helbing's social strength, Moussaïd [2] expands the relationship between pedestrians and pedestrians and adds the concept of a group. Then the social force expression of the pedestrian is

$$\overrightarrow{f_\alpha} = \overrightarrow{f_\alpha}^0 + \overrightarrow{f_\alpha}^{wall} + \sum_\beta \overrightarrow{f_{\alpha\beta}} + \overrightarrow{f_\alpha}^{group} \tag{22.3}$$

$$\overrightarrow{f_\alpha}^{group} = \overrightarrow{f_\alpha}^{vis} + \overrightarrow{f_\alpha}^{att} + \overrightarrow{f_\alpha}^{rep} \tag{22.4}$$

In this formula, Mehdi distinguishes the influence of pedestrians in the group and pedestrians outside the group. The forces of the pedestrians within the group include the self-taking power $\overrightarrow{f_\alpha}^{vis}$ based on the adjustment of the field of view, the attractiveness, and repulsive force between the members in the group.

Based on the structure of the five-person group, this paper further refines the types of social forces within the group and adds the pedestrian force within the subgroup and the pedestrian force between the subgroups. Based on the different social relationships within the pedestrian group, this paper divides the internal structure of a group of five into three layers, including groups, subgroups, and pedestrians. As shown in the figure, A is the pedestrian group where pedestrian α belongs to, and there is a subgroup inside a and b pedestrian groups A. The pedestrian α belongs to the subgroup a. Then the social force expression of the pedestrian α is

$$\overrightarrow{f_\alpha} = \overrightarrow{f_\alpha}^{0} + \overrightarrow{f_\alpha}^{wall} + \sum_{\beta \epsilon a} \overrightarrow{f_{\alpha\beta}} + \overrightarrow{f_\alpha}^{group} + \overrightarrow{f_\alpha}^{subg} \tag{22.5}$$

where $\sum_{\beta \epsilon a} \overrightarrow{f_{\alpha\beta}}$ is the interaction force between pedestrian α and the homogenous group, and $\overrightarrow{f_\alpha}^{subg}$ is the interaction force between pedestrian α and other subgroups in the same group. The formula is

$$\overrightarrow{f_\alpha}^{subg} = D \cdot exp\left(\frac{\left|d_{\alpha b} - d^*_{\alpha b}\right|}{C}\right) \cdot \overrightarrow{e_{\alpha b}} \tag{22.6}$$

where $d_{\alpha b}$ is the real-time distance between pedestrian α and the centroid of the subgroup b, $d^*_{\alpha b}$ is the expected distance between pedestrian α and the centroid of the subgroup b, and $\overrightarrow{e_{\alpha b}}$ is the direction of the force. The parameter D is a parameter for judging whether the force is attractive or repulsive according to the distance, and the parameter C is a parameter for controlling the strength (Fig. 22.1).

22.3 Results and Discussion

Pedestrian experimental site is shown as Fig. 22.2.

The width of entrance is defined to ensure the conditions of free flow. And the passage width is gradually reduced from 6 to 1.5 m. The length of limit part is 13 m, and the exit part is 7 m, for a total of 20 m. The experimental participants were college students at Tongji University, and 60 students were asked to be divided into 12 groups of 5 people.

22.3.1 Comparison by Passing Strategies

Based on the previous narrow passages of the five-person group through experiments [6], we found two main strategies that groups choose commonly by summarizing

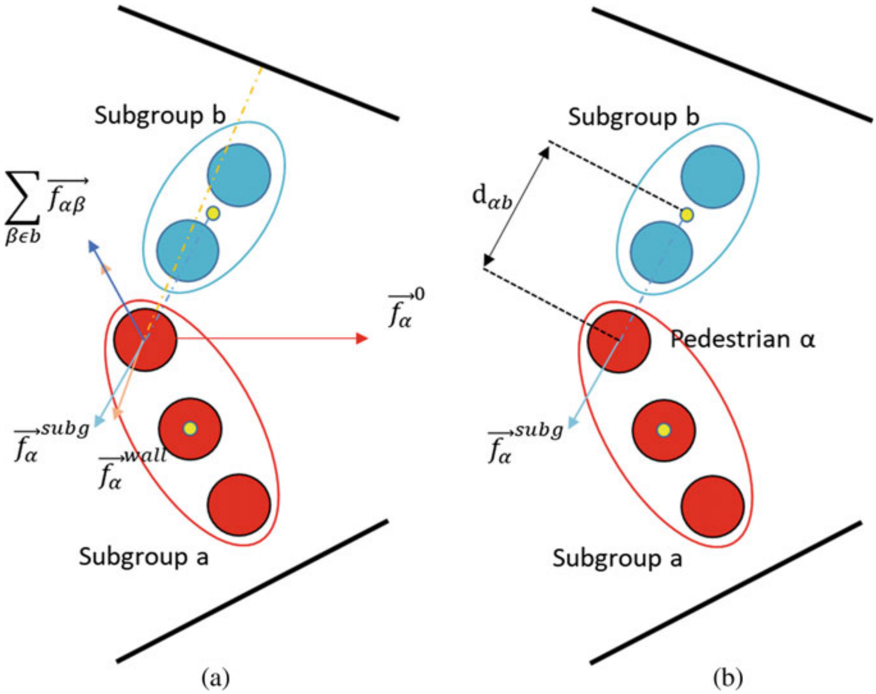

Fig. 22.1 The display of the five-person group under the narrow passage scene. **a** The analysis of pedestrian α in the narrow passage. **b** The influence of subgroup **b** on pedestrian α.

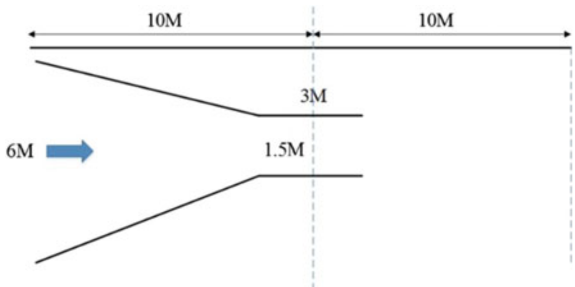

Fig. 22.2 Pedestrian experimental narrow passage

the trajectories of pedestrians. One is keeping the complex group configuration in which the subgroups keep relatively fixed positions to maintain a integrity structure of the complex group. Another is keeping the subgroup configuration in which the pedestrians in a subgroup maintain a relatively fixed structure and the subgroups adjust their relative positions (Fig. 22.3).

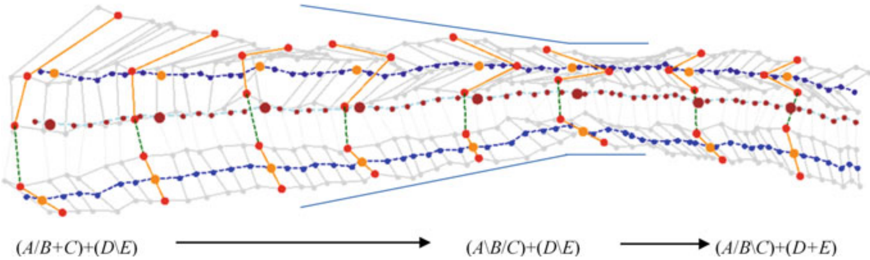

Fig. 22.3 Trajectories in experiments using strategy of keeping complex group configuration

Strategy of Keeping the Complex Group Configuration

The orange line is the pedestrian group structure line, the blue point is the changing trajectory of the centroid point position of the pedestrian subgroup structure, the wine-red point is the changing trajectory of the centroid position of the pedestrian group structure, and the gray line is the position change trajectory of the pedestrian.

The blue dots in Fig. 22.4 are members who belong to the same subgroups, and the red dots are members in another same subgroup. When pedestrians were passing about 1 m before getting close to the narrow passage, it can be seen that when approaching the narrowest position of the passage, the outer pedestrian tends

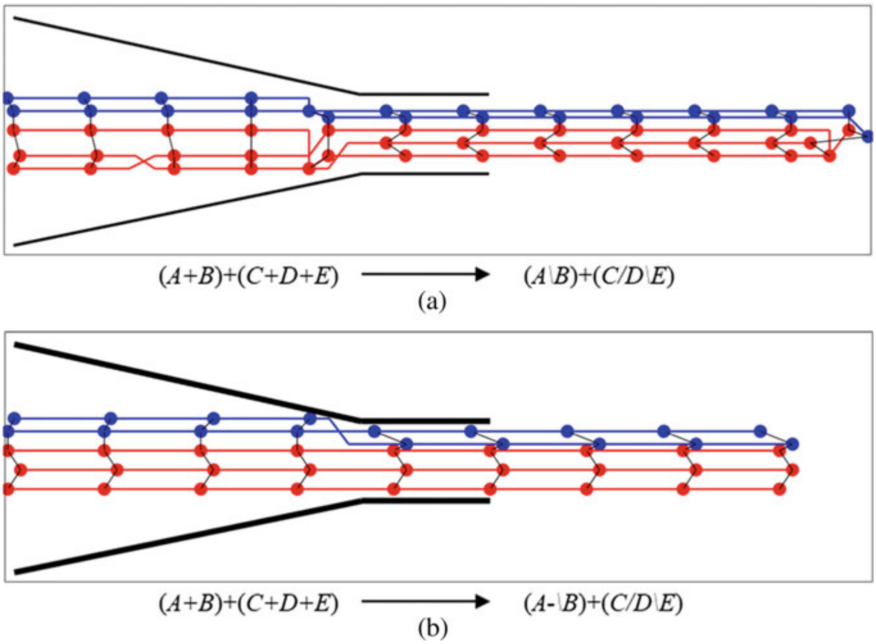

Fig. 22.4 Trajectories in simulation using strategy of keeping complex group configuration

to close inward to compress the space. However, due to space constraints, the position between the individuals become staggered—finally, the whole structure of the heterogeneous groups still in the V-shaped. So in the reorganization area, the strategy in the experiments is consistent with the simulations.

Strategy of Keeping the Subgroup Configuration

In this strategy, the positional relationship between subgroups change, and the left–right relationship becomes the front-rear relationship. While the groups walk from the wide side to the narrow side, as shown in Fig. 22.5, the data [6] shows that 70.2% of the constant groups preferred to keep stable configurations of subgroups, which makes 54.1% of all the complex groups. The simulation result of the passing strategy is shown in Fig. 22.5.

In the simulation, the most influencing factors adopted by the pedestrian group using different strategies are the parameter setting of the wall force and the parameter setting of the social force within the group. When the repulsive force from the wall is as same as the strength of the social force, and even when the social strength of the group is higher, the strategy tends to keep the group structure stable; when the wall strength is higher, the strategy tends to keep the subgroups structure stable. Besides, because the interaction between group members is relatively stable, this study tends to attribute the changing conditions affecting the strategy to the wall

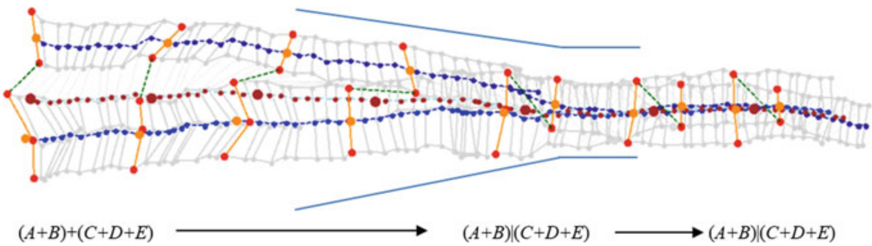

Fig. 22.5 Trajectories in experiments using strategy of keeping subgroup configuration

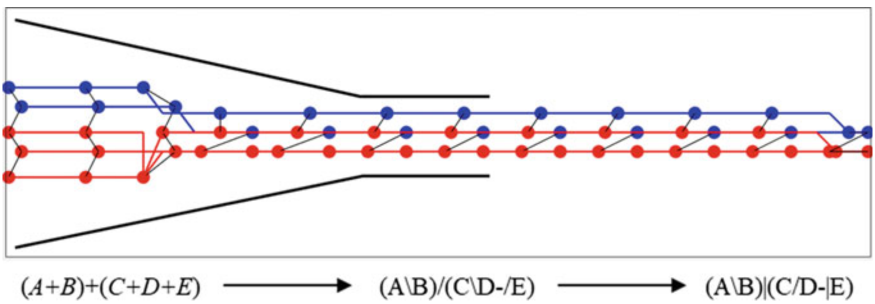

Fig. 22.6 Trajectories in simulations using strategy of keeping subgroup configuration

force. The introduction of random factors in the wall force formula, which controls the probability of occurrence of different strategies, could be helpful to the quantitative analysis and pedestrian experiments. This will be refined in the next step of the study.

22.4 Conclusion

Based on the research basis of the Expression-Matrix and structure of the five-person group, this study attempts to study the heterogeneous groups containing subgroups by using the extended social force model, measure, and record the changing process of group structure by the Expression-Matrix method.

Based on the predecessor model, the extended social force model used in this paper adds the force between other subgroups in the group and the pedestrian individual, by refining the pedestrian relationship in the multiple subgroups. At this point, the initial individual interaction between the pedestrians is subdivided into inter-group forces, inter-subgroup forces, and the interactions between pedestrians within the subgroup based on social relationships. It is worth mentioning that the past formula based on Newton's second law is no longer applicable to the analysis within the group. Because there is a need to maintain a certain distance between the subgroups, and the force contains attraction and repulsion both. Therefore, this requires some improvement in the expression of the subgroup force.

This study is based on Matlab and simulates a single group which contains two subgroups in a scenario that passing through a narrow passage. Through comparison with experimental data, the simulation has better restored the trajectory change process at the macro level and the adoption strategy of the group. The simulation results show that the improved social force model has particular applicability, and the calculation model of the force for maintaining the distance between the subgroups is more accurately.

At the same time, there are still many shortcomings in this study. For a narrow passage scenario of a single complex group, the trajectory is less sensitive to parameters due to the smaller scene with a slight change. Due to the time constraints, this study only focuses on a single complex group. In further research, the extended social force model could be placed on the application in crossing obstacle scenarios, as well as trajectory comparison, parameter calibration, and multiple complex pedestrian groups movements in various scenarios.

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