Easing Pedestrian Jam for Preventing Global Warming

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I. INTRODUCTION

Pedestrian Dynamics is studied by simulations and experiments vigorously over last decades [1, 2]. The main goal of the study is to solve the congestion in the city and find the safety way to evacuate in the emergency situation. However, easing the pedestrian jam does not solve these problems, but is also effective to save the energy and prevent the global warming.

It is said that one human has same power as a 100 [W] light ball. Thus, the temperature of a place, where many people are gathering, is higher than a vacant place, and need much energy for air conditioner. For example, the congested commuters' trains in Japan use a lot of energy for air conditioner in summer. Therefore, we can save energy for air conditioner by dispersing people.

In summer, large buildings such as theaters use air conditioner to cool inside of them. However, when many people get out from them, warm air comes into the buildings. Therefore, we can decrease it coming into the buildings by shorten the total egress time by applying the way of shortening the evacuation time in emergency situation, and save the energy for air conditioner.

We consider how pedestrians disperse and the way of fast evacuation. We will show how people disperse in the case there are two exits by the theoretical analysis. We find that the egress time is shortened when people evacuate in several lines than when people go out freely and also verify that putting an obstacle is effective for the fast evacuation. The both cases are studied by the experiments and the theoretical analysis.

II. THE WAY OF PEOPLE DISPERSING

We consider the situation as in Fig. 1 (a). Eighteen pedestrians try to get out from the room. There are two exits which are Exit A and Exit B, and Exit A is much nearer than Exit B for the pedestrians. If the all pedestrians go to the Exit A, a big jam is formed and the temperature around the Exit A goes up (Fig. 1 (b)). It is stressful for them to stay for a while in the jam. If the pedestrians disperse to the two exits, the size of the jam becomes much smaller (Fig. 1 (c)). The total evacuation time is also shorter in the dispersion case (Fig. 1 (c)) than the concentration case (Fig. 1 (b)).

We analyze how people disperse by using game theory.

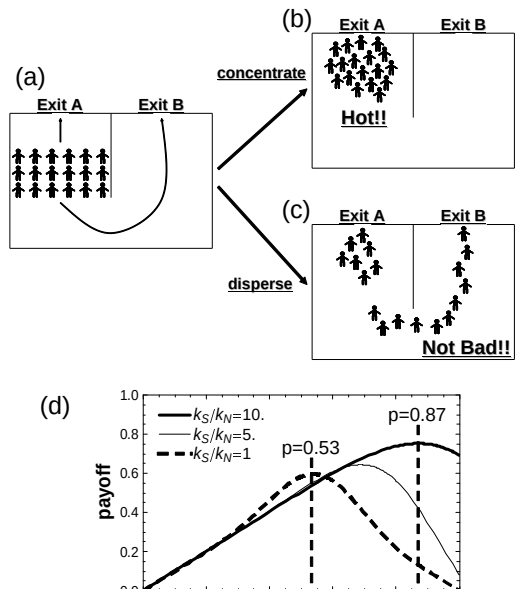

FIG. 1: (a), (b), and (c) Schematic views of the evacuation from the room, which has two exits. (d) The value of payoff as a function of p.

The payoff function of the pedestrians is determined as payoff$(S_X, N_X) = \exp(\quad k_S S_X \quad k_N N_X)$, where S_X is the distance to the Exit X, N_X is the number of pedestrians going to the Exit X, k_S is the pedestrians' intensity of going to the nearest exit, and k_N is the pedestrians' intensity of avoiding the congestion. Since S_X and N_X are multiplied by minus signs, payoff decreases when S_X and N_X increases. Thus, if a pedestrian choose a near exit and there are few other pedestrians, he/she can get large payoff. We decide p as the probability of going to the Exit A, i.e., the pedestrian go to the Exit B with probability $1 \quad p$. Figure 1 (d) shows the payoff as a function of p in the case $k_s/k_N = 10,\ 5,\ 1$, $S_A = 1$, and $S_B = 3$. We clearly find that the maximum payoff is attained at the value of p. We call it optimal p notated as p_{opt} here after. In the case $k_s/k_N = 10$, i.e., the pedestrians tend to choose the nearest exit without considering a congestion, the value of $p_{opt} = 0.87$, therefore most of the pedestrians go to the Exit A. However in the case $k_s/k_N = 1$, i.e., the pedestrian try to avoid a congestion as well as

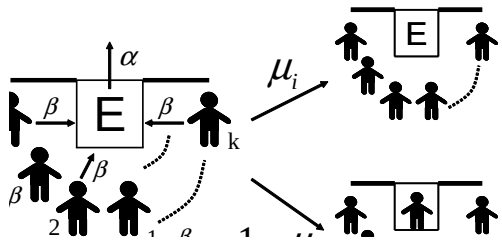

FIG. 2: Schematic view of the extended model at the exit.

go to the nearest exit, the value of $p_{opt} = 0.53$, therefore pedestrians disperse to the two exits.

III. THE RELATION BETWEEN PEDESTRIAN OUTFLOW AND A WAY OF EVACUATION

We consider a situation that every pedestrian in a room moves to the same one exit. We extend the floor field model [3] to focus on the pedestrians' behavior at the exit (Fig. 2). The normal floor field model uses the Neumann neighboring cells, however, we consider the situation that there are n neighboring cells of the exit cell and k pedestrians are trying to move to the exit cell. The case $n = 3$ and $n = 5$ corresponds to the FF model using the Neumann neighborhood and Moore neighborhood, respectively. The transition probability to the exit cell determined by the Static FF is represented as $\in [0, 1]$ for simplicity. $\in [0, 1]$ is a probability of getting out through the exit.

We consider three new factors to reproduce the realistic pedestrians' behavior at the exit.

First, we introduce the clogging and sticking effect by the *friction function*.

Due to the use of parallel dynamics of the floor field model, it happens that two or more pedestrians choose the same target cell in the update procedure. Such situations are called conflicts in this paper. To describe the dynamics of a conflict in a quantitative way, *friction parameter* $\mu_0 \in [0, 1]$ was introduced in Ref.[4]. It describes clogging and sticking effects between the pedestrians. In a conflict the movement of *all* involved pedestrians is denied with probability μ_0, i.e., all pedestrians remain at their cell. Therefore, the conflict is solved with probability $1 \quad \mu_0$, and one of the pedestrians is allowed to move to the exit cell (Fig. 2). The pedestrian which actually moves is then chosen randomly with equal probability.

However, the friction parameter, which represents the strength of clogging and sticking between pedestrians, is a constant and does not take account of the difference of the number of the pedestrians involved in the conflict. In reality, the clogging effect is stronger when three pedestrians conflict each other than when two pedestrians conflict each other. Therefore, we newly introduce the friction function μ_1 and μ_2, which are functions of $k \in \mathbf{N}$, i.e., the number of pedestrians involved in the conflict. μ_1 and μ_2 are described as follows:

$$\begin{aligned} \mu_1(\zeta_1, k) &= 1 \quad \exp[\ \zeta_1(k \quad 1)] \\ \mu_2(\zeta_2, k) &= 1 \quad (1 \quad \zeta_2)^k \quad k\zeta_2(1 \quad \zeta_2)^{k-1}. \end{aligned} \tag{1}$$

$\zeta_1 \in [0, \infty)$ and $\zeta_2 \in [0, 1]$ are friction coefficient, which represent the strength of the clogging irrelevant to k. When ζ_1 and ζ_2 increases, μ_1 and μ_2 increase, respectively. The details of μ_1 and μ_2 are described in Ref. [5].

The second factor is the effect of turning around at an exit. The pedestrians, who move to the exit cell from lateral direction as the pedestrian 1 and k in Fig. 2, have to turn their face to the outside of the room at the exit cell to get out from the room, thus their walking speed decreases. The third factor is the zipper effect. When many pedestrians egress through the narrow exit, we often see that pedestrians in the left area and pedestrians in the right area go through the exit one after the other, and the outflow increases since the number of conflicts between pedestrians deceases dramatically. This phenomenon is called zipper effect. We introduce these factors to the model. The details of them are described in Ref. [6].

We did the evacuation experiments (Fig. 3) to verify the relation between the three new factors and the average pedestrian outflow $\langle q \rangle$ [persons/(m · sec)], which is the average number of pedestrians going through the 1 [m] width exit in 1 [sec].

The results of the experiments and theoretical analysis are described in Fig. 4. There are three remarkable points in this figure. First, we see that the pedestrian outflow decreases in $n \quad 2$. This indicates that when the number of pedestrians at the neighboring cells of the exit increases, the outflow decreases. Second, the maximum outflow is attained in the case (B), i.e., two-parallel-line case. We observe the zipper effect, i.e., pedestrians in the left line and the right line go through the exit one after the other, in our video. Pedestrians are intelligent enough to avoid conflicts by their selves. Third, the pedestrian outflow in the case (G) ($n = 4$) and the average of pedestrian outflow in the case (H) and (I) (Fig. 4 (H&I)) are similar. This indicates that there are approximately four pedestrians at the exit in the normal evacuation situation (H) and (I) when the width of the exit is 50 cm.

Comparing the theoretical and experimental results, we see that the results of the friction functions agree with those of the experiments very well, however, the results of the friction parameter does not. Since the friction functions consider the difference of n, they reproduce the value of the experiments, while the friction parameter does not.

IV. THE EFFECT OF AN OBSTACLE

We study the effect of an obstacle put in front of the exit in this section. We did the two kind of evacuation

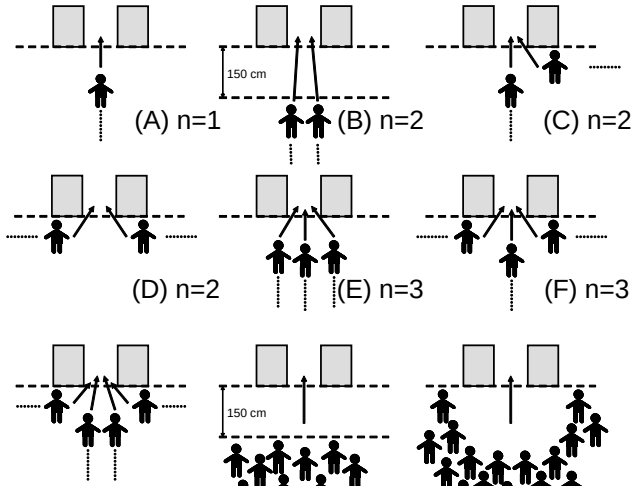

FIG. 3: Schematic views of nine initial conditions of the experiments.

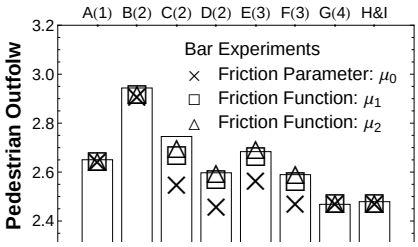

FIG. 4: Pedestrian outflows of the experiments and the theoretical calculation using μ_0, μ_1, and μ_2.

experiments at the NHK TV studio in Japan. In one case, pedestrians egress from the room through the 50 [cm] exit as in Fig. 5 (a) and the other case, pedestrians egress from the room through the 50 [cm] exit with an obstacle as in Fig. 5 (b).

The pedestrian outflow in the case (a) is 2.75 and that in the case (b) is 2.93. We surprisingly find that the outflow of the experiment (b), i.e., the experiment putting an obstacle in front of the exit, is larger than the experiment (a), which is a normal evacuation.

We explain this phenomenon by our theory. Looking the video of the experiments, we see that the obstacle blocks the participant moving to the exit. In the Sec. III, we found that in the normal evacuation there are approximately four pedestrians at the exit, i.e., $n = 4$ in the experiment (a) (Fig. 5 (a)). When the obstacle is put in front of the exit, there are approximately three pedestrians at the exit, since it blocks one pedestrian moving to the exit. Therefore, we consider that $n = 3$ in the experiment (b) (Fig. 5 (b)). We obtain the value of the pedestrian outflow from the theoretical analysis as follows: (Case μ_0: 2.75), (Case μ_1: 2.94), and (Case μ_2: 3.00). We find that the pedestrian outflows of the friction functions μ_1 and μ_2 agree with that of the experiment (b) well again, while the pedestrian outflow of the friction parameter is much smaller. This result justifies our assumption that the obstacle increase the pedestrian outflow since it decreases n, which is the number of pedestrians at the neighboring cells of the exit cell.

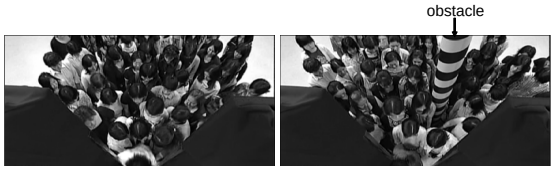

FIG. 5: Snap shots of the experiments. (a) Normal evacuation. (b) There is an obstacle in front of the exit.

V. CONCLUSION

In the former part in this paper, we study how pedestrian disperse to the two exits. In the latter part, we introduce the *friction function*, which changes its value against the number of pedestrians involved in a conflict. By using the friction functions, we obtain the more realistic figure of the pedestrian outflow through an exit, which corresponds to the result of the experiments very well. We have also found that the evacuation in the two-parallel-line case is the fastest and that the pedestrian outflow increases by putting an obstacle in front of the exit in the experiments.

Acknowledgements

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