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JOCS-535; No. of Pages 8
ARTICLE IN PRESS
Journal of Computational Science xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Journal of Computational Science
journal homepage: www.elsevier.com/locate/jocs

Influence of agents heterogeneity in cellular model of evacuation

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ARTICLE INFO

Article history:
Received 15 March 2016
Received in revised form 24 May 2016
Accepted 6 August 2016
Available online xxx

Keywords:
Travel time
Floor-Field model
Aggressiveness
Bonds principle
Heterogeneity
Pedestrian dynamics

ABSTRACT

The influence of agents heterogeneity on the microscopic characteristics of pedestrian flow is studied via an evacuation simulation tool based on the Floor-Field model. The heterogeneity is introduced in agents velocity, aggressiveness, and sensitivity to occupation. The simulation results are compared to data gathered during an original experiment. The comparison shows that the heterogeneity in aggressiveness and sensitivity to occupation enables to reproduce high variance of travel-time in congestion. This variance is closely related to the ability of some pedestrians to push effectively through the crowd or walk around it. The heterogeneity in velocity seems to be redundant.

1. Introduction

The presented study of the heterogeneity in CA models directly extends the contribution on aggressiveness presented in [1]. Detailed study of the heterogeneity in more aspects of agents in Floor-Field model is based on empirical observations related to variety of experiments conducted by our research group [2–4]. We aim to investigate, whether some microscopic aspects of the pedestrian flow can be mimicked introducing heterogeneity to some parameters of Floor-Field model.

The experiments mentioned above were designed to study the boundary induced phase transition, which has been analysed theoretically in [5] for Floor-Field model. The object of such study is a rather small room with one exit and multiple entrance, which may be considered as one segment of a large network. During the experiment, an important aspect of pedestrian behaviour has been observed: participants have different ability to push through the crowd, what leads to significant variance in the time spent by the pedestrian in the room.

The presented cellular model is based on the Floor-Field model [6–8] with *adaptive time-span* [9] and *principle of bonds* [10]. The adaptive time span enables to model heterogeneous stepping velocity of pedestrians; the principle of bonds helps to mimic collective behaviour of pedestrians in lines. For comprehensive summary of Floor-Field model modifications capturing different aspects of pedestrian flow and evacuation dynamics we refer the reader to [11].

In this article we focus on the heterogeneity in three aspects of the pedestrian flow: the desired velocity, aggressiveness (or ability to win conflicts), and sensitivity to occupancy (related to line formation).

2. Experiment

Presented simulation study leans over the experiment "passing-through", which set-up is schematically depicted in Fig. 1. Detailed analyses of the experiment with respect to microscopic aspects of pedestrian flow can be found in [3,4]. Selected results of the above-mentioned studies are summarized in this section. Videos capturing some aspects of the experiment are available at http://gams.fjfi.cvut.cz/peds.

The experiment simulated one room of a complex network with constant inflow caused by non-panic egress of pedestrians from the facility. Participants were instructed to walk through the rectangular room with one 60 cm wide exit and multiple entrance, the inflow of pedestrians α [ped/s] has been artificially controlled in order to investigate the boundary induced phase transition (more details in [3]). Thanks to varying value of the inflow rate α the pedestrian behaviour was observed under variety of conditions, from which the size of the crowd in front of the exit plays the main role. During each run of the experiment, pedestrians were passing repeatedly

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http://dx.doi.org/10.1016/j.jocs.2016.08.002
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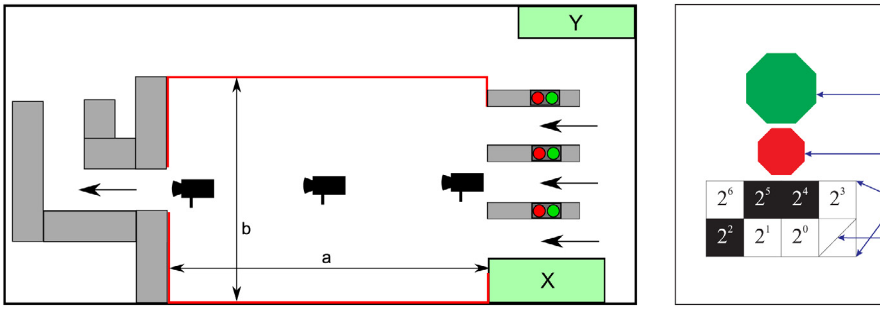

Fig. 1. Left: setting of the experiment, $a = 7.2$ m, $b = 4.4$ m. Right: sketch of pedestrian's hat used for automatic image recognition.
Source: Taken from [3].

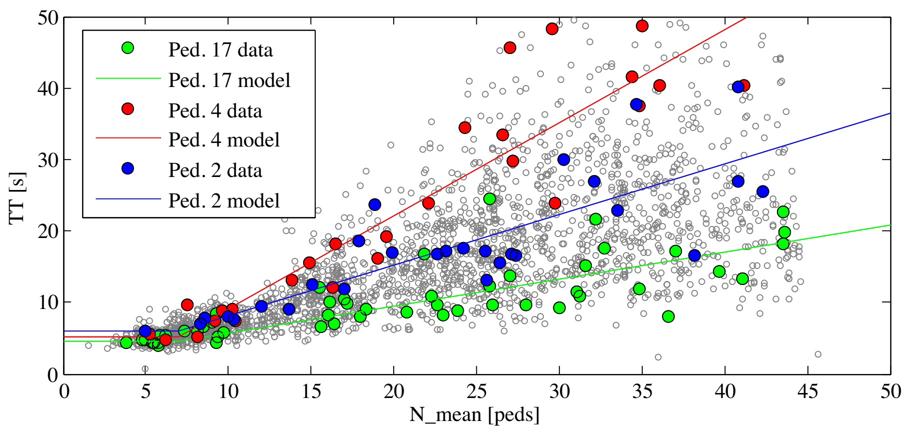

Fig. 2. Scatter plot of the travel time *TT* with respect to the occupancy N_{mean} extracted from the experiment. Three participants are highlighted. Their travel time is approximated by the piecewise linear model (2). We can see that Ped. 2 has lower desired velocity in free regime but higher ability to push through the crowd in comparison to Ped. 4.
Source: Taken from [4].

through the room in order to keep stable inflow for sufficiently long time. Due to that there are 20–40 records for each participant. Moreover, the unique codes assigned to all participants enabled the study of individual properties of the pedestrians.

Usually the maximal outflow/capacity of the bottleneck is related to its width *b*. In [12] the dependence is suggested $J_{\max} = 1.9 \times b$. Here we note that the measured capacity of the bottleneck in the experiment was approximately 1.4 ped/s, which is higher than suggested value 1.9 × 0.6 ped/s. It was caused by high motivation of pedestrians to exit the room and by the fact that the narrowing was followed by a slightly wider corridor. Despite that the motion of pedestrians within the following corridor was strictly one-lane without overtaking.

2.1. Travel-Time

The key investigated quantity is the travel time *TT* denoting the time interval between the entrance at T_{in} and the egress at T_{out} of each pedestrian, i.e., $TT = T_{\text{out}} - T_{\text{in}}$. To capture the pedestrians behaviour under variety of conditions, the travel time is investigated with respect to the average number of pedestrians in the room N_{mean} defined as

$$N_{\text{mean}}(T_{\text{in}}, T_{\text{out}}) = \frac{1}{T_{\text{out}} - T_{\text{in}}} \int_{T_{\text{in}}}^{T_{\text{out}}} N(t)\mathrm{d}t, \tag{1}$$

where $N(t)$ stands for the number of pedestrians in the room at time *t*. As expected the average *TT* increases with respect to the number of pedestrians in the room *N*, referred further as the occupancy. Surprisingly, the variance of the *TT* increases dramatically with occupancy as well.

Fig. 2 shows the scatter plot of all pairs (N_{mean}, *TT*) gathered over all runs of experiment and all participants. Records corresponding to three chosen pedestrians are highlighted. We can observe that the reaction of participants to the occupancy *N* significantly differs. The mean travel time in the free-flow regime (0–7 pedestrians) reflects the pedestrian desired velocity; the slope of the travel-time dependence on the occupation *N* in the congested regime (10–45 pedestrians) reflects the pedestrian ability to push through or walk around the crowd. This observation corresponds to the piece-wise linear model for each pedestrian

$$TT = \frac{S}{v_0(i)} + \mathbf{1}_{\{N>7\}}(N-7)\cdot \text{slope}(i) + \text{noise} \tag{2}$$

where $S = 7.2$ m, $v_0(i)$ is the free-flow velocity of the pedestrian *i*, slope(i) is the unique coefficient of the linear model for pedestrian *i*. The breakpoint $N = 7$ depends on the room geometry. The weighted mean of the R^2 value of the model (2) is 0.688.

2.2. Heterogeneity and Travel-Time

The high variance of the *TT* caused by the heterogeneous reaction to crowd is reflected in the distribution of the relative travel-time $TT_R = TT/\bar{TT}(N)$, where $\bar{TT}(N)$ is the average of records corresponding to occupancy $N_{\text{mean}} \in (N-1, N]$. Fig. 3 presents the histograms of TT_R for free flow regime (0–7 pedestrians) and for congested regime (30–50 pedestrians).

There are two aspects explaining the high variance of the *TT* accompanied with extremely low and high values in congested regime: the aggressiveness and better path choice. We have observed that some of the pedestrians were pushing effectively