Physica A 458 (2016) 31–42

Contents lists available at ScienceDirect

Physica A

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

Effect of speed matching on fundamental diagram of pedestrian flow

Zhijian Fu [a,b,c], Lin Luo [c], Yue Yang [d], Yifan Zhuang [c], Peitong Zhang [a], Lizhong Yang [c,e,*], Hongtai Yang [a,b], Jian Ma [a,b,**], Kongjin Zhu [f], Yanlai Li [a,b]

[a] *School of Transportation and Logistics, Southwest Jiaotong University, Chengdu, 610031, PR China*
[b] *National United Engineering Laboratory of Integrated and Intelligent Transportation, Southwest Jiaotong University, Chengdu, 610031, PR China*
[c] *State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, 230026, PR China*
[d] *School of the Gifted Young, University of Science and Technology of China, Hefei, 230026, PR China*
[e] *Collaborative Innovation Center for Urban Public Safety, Hefei, 230009, PR China*
[f] *School of Transportation Engineering, Hefei University of Technology, Hefei, 230009, PR China*

HIGHLIGHTS

- By a modified CA, the simulation fits well with the empirical FD.
- A diverse composition of pedestrian improves pedestrian flow.
- Speed matching decreases the conflict density.

ARTICLE INFO

Article history:
Received 14 February 2016
Available online 7 April 2016

Keywords:
Pedestrian dynamics
Fundamental diagram
Collective motion
Cellular automaton
Speed matching

ABSTRACT

Properties of pedestrian may change along their moving path, for example, as a result of fatigue or injury, which has never been properly investigated in the past research. The paper attempts to study the speed matching effect (a pedestrian adjusts his velocity constantly to the average velocity of his neighbors) and its influence on the density–velocity relationship (a pedestrian adjust his velocity to the surrounding density), known as the fundamental diagram of the pedestrian flow. By the means of the cellular automaton, the simulation results fit well with the empirical data, indicating the great advance of the discrete model for pedestrian dynamics. The results suggest that the system velocity and flow rate increase obviously under a big noise, i.e., a diverse composition of pedestrian crowd, especially in the region of middle or high density. Because of the temporary effect, the speed matching has little influence on the fundamental diagram. Along the entire density, the relationship between the step length and the average pedestrian velocity is a piecewise function combined two linear functions. The number of conflicts reaches the maximum with the pedestrian density of 2.5 m^{-2}, while decreases by 5.1% with the speed matching.

1. Introduction

Collective motion is quite common in the nature. Schools of fish move in rather orderly way or change direction abruptly. Another example is that a group of feeding pigeons will order themselves into an orderly flying flock when leaving the

---

[*] Corresponding author at: State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, 230026, PR China. Tel.: +86 551 63606416.

[**] Corresponding author at: School of Transportation and Logistics, Southwest Jiaotong University, Chengdu, 610031, PR China.

E-mail addresses: yanglz@ustc.edu.cn (L. Yang), majian@mail.ustc.edu.cn (J. Ma).

http://dx.doi.org/10.1016/j.physa.2016.03.060
0378-4371/

scene after a big disturbance [1]. The main feature of collective behavior is that an individual's action is dominated by the influence of "others" [2]. Collective motion is also common in pedestrian movement, representing itself as self-organization phenomena like lanes formation, arching, herding and so on [3–6]. Despite the physiological function and psychological behavior discrepancies among pedestrians, they share some similarities: (1) collision avoidance; (2) flock centering; (3) velocity matching: attempt to match with the surrounding pedestrians' velocity. Although the interaction between the pedestrian and other surrounding pedestrians is local, the crowd motion is complex. As a vector quantity, velocity is the combination of direction and speed. As for the direction matching, pedestrians have the tendency to move with the directions as other pedestrians in the neighborhood [7,8], representing as gathering [9] or going with the crowd [10] during evacuation. We only discuss the speed matching where a pedestrian tends to move with the same speed as his neighbors, thus, to reduce the conflicts and to enhance the traffic capacity. That is common in rush hours. For example, a person might have to speed up because pedestrians around him walk much faster. We try to investigate if that speed matching have an influence on the ρ–v relationship of pedestrian dynamics.

The empirical relationship between the velocity and the density of pedestrian movement is known as the fundamental diagram (FD), one of the most important subjects in the study of pedestrian dynamics [11,12]. During last decades, researchers studied the FD based on experiments [5,12–21], while the fundamental diagrams can be quite different even under the same experimental condition [17–21]. Additionally, explanations for these discrepancies are not consistent, some of which are even contrary, indicating that the empirical correlation is still not completely understood. Such explanations include culture differences [22,23], differences between uni-direction and multi-direction flow [16,20,21,24,25], short-ranged fluctuation [25], and other psychological factors [26,27]. We explored the FD discrepancies from the view of the pedestrian microscopic behavior, and found that the random slowdown behavior and lock-step effect have a significant influence on the curve configuration and characteristic parameters of the FD [11]. However, FD discrepancies are still not clear. Here, we explored the speed matching and collective behavior in pedestrian flow, and how they affect the fundamental diagram and reduce the conflicts.

2. Methods

Pedestrian and evacuation dynamic (PED) models can be classified into continuous models and discrete models based on space discretization [5]. Fluid dynamic and gas kinetic models [28–31] and social force models [6,32–34] are typical continuous models, whereas cellular automaton (CA) models [35–38] and lattice-gas models [39–43] are typical discrete models. As a kind of discrete microscopic PED models, the floor field CA model, an extension of asymmetric simple exclusion process (ASEP), has its specific advantages in the extendibility, reproducing crowd self-organized phenomena, embodying individual properties, and reducing the computing complexity by translating the long-ranged interaction to local interaction [44–46]. It plays an important role in the study of PED.

2.1. Floor field cellular automaton

Pedestrians make their decisions according to the so-called transfer probability which is determined by both the static field S and the dynamic field D [36,47]. The Moore neighbor and a synchronous/parallel update pattern were used [48]. The transfer probability is calculated by

$$P_{ij} = N \exp(K_D D_{ij} + K_S S_{ij})(1 - n_{ij}) M_{ij} \varepsilon_{ij} d_{ij} \tag{1}$$

where N is the normalization factor to make sure $\sum_{ij} P_{ij} = 1$. n_{ij} is the occupied rate of the cell (i, j). Here, $n_{ij} = 1$, if cell (i, j) is occupied by a pedestrian, otherwise $n_{ij} = 0$. ε_{ij} reflects the obstacle influence. $\varepsilon_{ij} = 0$, if cell (i, j) is occupied by obstacle, otherwise $\varepsilon_{ij} = 1$. The preference of pedestrians is not considered in this study so that the preference matrix M_{ij} is set as a unit matrix. d is the inertial factor to enhance the transition probability in the previous direction. K_S, K_D are the coefficient of the static field and the dynamic field respectively. The static field is structured using the method proposed in Ref. [45]. The dynamic field can be regarded as a virtual trace left by pedestrians at the previous time step with diffusion and decay [35].

2.2. Multi-velocities and conflicts resolution

Desired velocities of pedestrians might be quite different due to the discrepancies of the physiological function, including age, gender, physical state, and the psychological behavior, such as the perception and reaction to the danger environment. Additionally, a pedestrian might change his velocity constantly to adapt to the changing environment like speed matching. However, it has been hard to simulate a pedestrian flow with various changing speeds using a synchronous discrete PED model. That is because the cross and overlaps of routes have to be taken into consideration and the conflict resolution between pedestrians is more complex. Many researchers tried to make it easier. But most of their models are limited in extendibility [49–51], and require high computing power [52,53], or are difficult to calibrate [39,53]. Thus, the velocity ratio was applied with the synchronous updated floor field CA.