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Experimental Study of Phase Transition in Pedestrian Flow

M. Bukáček [a,*], P. Hrabák [a,b], M. Krbálek [a]

[a] *Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Trojanova 13, 120 00 Prague, Czech Republic*
[b] *Institute of Information Theory and Automation, Academy of Sciences of the Czech Republic, Pod Vodarenskou vezi 4, 182 08 Prague, Czech Republic*

Abstract

The transition between low and high density phases is a typical feature of systems with social interactions. This contribution focuses on simple evacuation design of one room with one entrance and one exit; four passing-through experiments were organized and evaluated by means of automatic image processing. The phase of the system, determined by travel time and occupancy, is evaluated with respect to the inflow, a controlled boundary condition. Critical values of inflow and outflow were described with respect to the transition from low density to congested state. Moreover, microscopic analysis of travel time is provided.

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1. Introduction

Different aspect of pedestrian behaviour have been studied last ten years. The coexistence of different phases of crowd motion (Seyfried et al. (2010)) and associated phase transition is studied mostly by means of fundamenthal diagrams, relations between density and flow, or velocity (Schadschneider and Seyfried (2009), Schadschneider et al. (2010)). The pedestrian flow (or traffic in general) is mainly affected by so called bottleneck, a part of the facility, where is the wide corridor or room connected to some narrow part or exit (Seyfried et al. (2009)). There are other significant aspect of pedestrian motion: cross-sections (Kretz (2014)), T-junctions (Boltes et al. (2011)) or waiting zones (Davidich et al. (2013)).

In this article we consider a simple rectangular room with one multiple entrance and one exit placed on the opposite wall. This room can be considered to be a single passing-through segment of a large complex facility (Was and Lubaś (2013)), e.g a corridor with bottleneck on the egress site. The common idea of all presented experiments is as follows: at the beginning the room is empty; after the initiation (start of the evacuation, end of the football match, etc.) pedestrians are entering the room in order to pass through. Let us further consider that the width of the exit is fixed and pedestrians are entering the room with given inflow rate α [pedestrians/second = ped/s] which is the only free parameter of the system.

By means of such experiments we aim to answer following questions:

* Corresponding author. Tel.: +420 224 358 567; fax: +420 234 358 643
E-mail addresses: bukacma2@fjfi.cvut.cz (M. Bukáček)., hrabak@utia.cas.cz (P. Hrabák)., milan.krbalek@fjfi.cvut.cz (M. Krbálek).

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1. What is the mechanism of the transition from the free flow through the room to the congestion in front of the exit?
2. How does the transition relates to the inflow rate α?
3. What is the saturation value α_S?
4. How does the saturation reflects in the macroscopic quantities as average occupation of the room and average travel-time through the room?
5. How is the phase transition related to microscopic personal characteristic (e.g. pedestrian travel time, time headway at the doors)

Related studies have been presented in Bukáček et al. (2014a) and (Bukáček et al., 2014b). In this article improved method for automatic pedestrian detection is presented, which enables better and more reliable recording of microscopic quantities as travel time through the room or pedestrian velocity. Furthermore, every pedestrian can be identified by unique code, therefore it is possible to discuss their individual properties according to the motion inside the crowd.

The idea of studying such open room is inspired by the work Ezaki et al. (2013), where a phase transition from low to high density is studied by means of the Floor Field model in similar environment as the room setting discussed in this article. The phenomenon of boundary induced phase transition is often observed in interacting particle systems and similar agent-based simulations (Bukáček and Hrabák (2014)). By the boundary conditions we understand the narrow exit (60 cm in presented experiment) limiting the outflow and the variable inflow of pedestrians (1–2 [ped/s] in the experiments). In dependence on internal parameters as friction function parameter ζ, friction parameter μ, used updating scheme etc., the system evinces a saturation of the outflow after crossing over certain "saturation point", or critical value α_S of the inflow α. This leads to reaching the capacity of the corridor or room and results in creation of a growing cluster in front of the exit.

Such dependence on the inflow parameter is called phase transition in this article. It is important to note that there is another type of transition to be considered in such systems, and hence, the transition from the free flow at the beginning of the experiment or simulation to the congestion created after certain time of the system evolution. Such transition is not discussed in this document.

To compare the mechanism of the phase transition observed in simulations with the (semi)real system, four experiments were established at the Faculty of Nuclear Sciences and Physical Engineering (FNSPE) from 2012 to 2014. In the following, the experiments are indexed as E1, E2, E3, and E4. The first experiment E1 discussed in Hrabák et al. (2013) concerned with the egress situation only. In this article the results of time-headway evolution at the exit have been compared with the experiment E4. Experiments E2 and E3 focused mainly on fundamental diagram evaluation; the phase transitions were evaluated from the macroscopic point of view mainly, i.e., the creation of the stable cluster or growing congestion has been observed, for detail see Bukáček et al. (2014a) or Bukáček et al. (2014b). The experiment E4 was designed better to capture the phase transition by the change of the travel time through the room as well. The experimental setting is in detail described in section 2.

2. Experimental setting

The setting of experiments E2, E3, and E4 is depicted in Figure 1. Around 80 volunteers (second year students of FNSPE) were gathered in front of the exit. After initiation, the volunteers were instructed to enter the room at the green signal near the entrance and leave the room as fast as possible by walking (running and strong physical contacts were forbidden).

The observed room was equipped by three cameras: above the center of the room, above the entrance, and above the exit. During the experiment E4 emphasis has been put on automatic detection of pedestrians. Every pedestrian was equipped by a hat with unique binary code, as depicted in Figure 1. The pedestrian detection was performed by means of specific color recognition in each frame of the record. A semi-automatic software was used for the identification of the input and output of each pedestrian. Based on the manual comparison with the records in dens regime, the reliability of such detection is above 95 %. A snapshot from the experiment is presented in Figure 2.

To control the inflow rate α, the signalling device was used. Randomly long red signal was alternated by 0.1 s green signal, on which, certain number of pedestrians were forced to enter. In experiments E2 and E3, two or three pedestrians entered the room together. Based on the experiment E2 it has been observed that the ability of pedestrians