Crowd egress in high-density scenario

Ines Cilenti[1], Enrico Ronchi[1], Michele Fronterrè[2], Giuseppe G. Amaro[3]
[1]Lund University, Sweden
[2]Cantene Srl, Italy
[3]GAE Engineering, Italy

Large events can host thousands of people and it is therefore crucial to carefully plan for their egress. In this context, solutions can be adopted for the management of crowds in high-density scenarios, as issues related to safety and comfort can occur when high densities are present. It is therefore necessary to evaluate the relationship between the space available and the interactions among pedestrians in such conditions. Nevertheless, pedestrian movement data-sets on high-density conditions are scarce, and the few available data-sets are collected in very specific conditions [1].

It is important to note that the design of outdoor and indoor spaces for egress should not be based only on average global pedestrian density conditions, but it should consider also local densities and bottlenecks. In order to prevent critical conditions to occur, modelling tools can be a useful tool to identify optimal egress and investigate the impact of crowd management strategies. Despite their potential, their use for high density scenarios have gone through very limited scrutiny.

The first question to be answered relates to the definition of high density. To date, an accepted definition of high density does not exist, due to the large number of factors which affect the occurrence of high density conditions and their implications on safety. In addition, it is important to assess for how long a certain density level occurs in order to perform a safety assessment. In high-density conditions, the physical movement of people can be represented in continuous models [2] by considering the impact of individual characteristics on the emerging pedestrian flows. It is therefore important to identify the main variables affecting pedestrian density. In this study, we considered walking speed, comfort distance (intended here as the desired distance that people want to keep free from the presence of others) and body size distributions. Considering the impact of these variables and the available literature [3], [4], large variation exists in what is currently considered a high-density scenario. This can range from 2-6 persons/m^2 while extreme density can be defined as large as >6 persons/m^2.

One key issue to consider is that it can be difficult to simulate pedestrian movement in high and extreme density scenarios, as egress models often rely on assumptions and data-sets collected for much lower density levels [5]. For this reason, this study suggests the use of *ad hoc* data-sets to calibrate egress models. A relevant data-set is here obtained from field observations of an actual outdoor event including high density conditions. The data-set consisted of video recordings of pedestrian movement which have been used to obtain key information (e.g. movement speeds, flows and densities) about the movement of pedestrians in a high-density scenario. The data-set has then been employed to perform an iterative process of model calibration able to generate the observed high density conditions. The egress model Pathfinder [6] has been used for testing this procedure.

The field observations were performed in 2018 at an outdoor event in the city of Turin, Italy, involving approximately 35.000 people. The main area of the event was the city centre and the surrounding zones (see Figure 1). A video analysis tool was used to analyse the data (Figure 2) and measure pedestrian flows, speeds and densities.

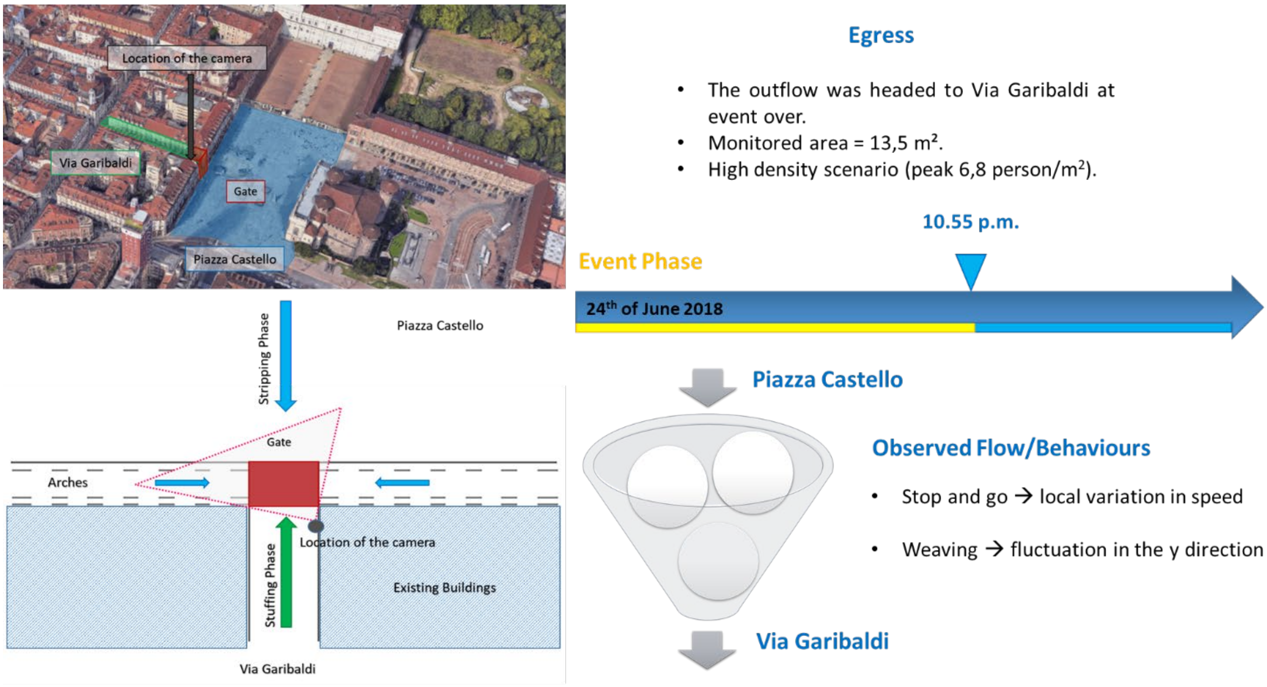

Figure 1. The top-left image (Google maps) shows the location of the event and the gate under consideration. This gate was used to leave the event. The bottom-left image shows the area under consideration and the directions of the pedestrian flows (the red area is the gate under consideration, with the dotted red lines representing the camera view and the black dot representing the location of the camera. Details of the Egress phase are presented in the right side of the figure, including the observed flows, e.g., weaving [7].

Figure 2. Left side: screenshot from the video analysis tool. The blue crosses in the photo on the left correspond to a person in the control area (those correspond to white circles in the zoomed area). Right side: schematic representation of the observed area: the red grid has been used to analyse the pedestrian movement and to facilitate the counting of the pedestrians present in the area in a specific time.

High local (dynamic) densities up to 7 persons/m^2 have been observed in critical points, i.e., bottlenecks, despite the controlled (static) densities observed in the area were in the range of 4 persons/m^2. Counter-flows combined with merging flows from the sides were observed and increased the local density in the bottleneck region.

A set of tests (42 model input configurations), using first the default input parameters and then introducing a range of input configurations were run with a continuous egress model (Pathfinder [6]). The scope was to investigate how such type of egress models should be calibrated in high density scenarios to reproduce the observed local densities and the flows recorded during the event.

In continuous models, one of the main factors affecting the obtainment of maximum densities higher than 4 persons/m^2 consists in the way the program represent the agents. As current models generally assume rigid bodies (i.e. agents cannot overlap or be deformed) of a given shape (generally a circle or an ellipsis) moving in a 2D/3D space, higher densities can be achieved by reducing the agent's body sizes and the comfort distances. However a careful process of input calibration is needed to allow for a more realistic set of density outputs without representing other pedestrian movement and behavioural aspects in a non-realistic manner.

The results of this work indicates that: 1) it is possible to achieve reasonable values of local density with continuous egress models by prescribing walking speeds, agents' body size, comfort distances and the initial density in the area; 2) setting the input parameters knowing key variables from high density field observations may lead to more realistic density results; 3) to date, one the main limitations of most egress models is the lack of representation of the impact of physical forces among pedestrians, which in turn can play an important role in pedestrian movement. This study therefore highlights the importance of not relying on default settings of egress models for high/extreme density scenarios as they are mostly based on data-sets collected on low-middle density levels. This is particularly important for the use of egress models for the assessment of crowd management solutions in high density scenarios, and to identify solutions/critical conditions ahead of the events.

This article is based on a thesis work made at Lund University within the International Master of Science in Fire Safety Engineering (IMFSE). Further details of the work performed are available in the final report presenting the thesis work [8].

[1] R. Lohner, B. Muhamad, P. Dambalmath, and E. Haug, "Fundamental Diagrams for Specific Very High Density Crowds," *Collect. Dyn.*, vol. 2, p. A13, Jan. 2018.
[2] E. Ronchi and D. Nilsson, "Basic Concepts and Modelling Methods," in *Evacuation Modeling Trends*, A. Cuesta, O. Abreu, and D. Alvear, Eds. Cham: Springer International Publishing, 2016, pp. 1–23.
[3] A. Johansson, D. Helbing, H. Z. Al-Abideen, and S. Al-Bosta, "From crowd dynamics to crowd safety: a video-based analysis," *Adv. Complex Syst.*, vol. 11, no. 04, pp. 497–527, 2008.
[4] M. Plaue, G. Bärwolff, and H. Schwandt, "On measuring pedestrian density and flow fields in dense as well as sparse crowds," presented at the Pedestrian and Evacuation Dynamics 2012, Zurich, 2012.
[5] J. J. Fruin, "Pedestrian Planning and Design," in *Metropolitan Association of Urban Designers and Environmental Planners (Revised Edition)*, 1987.
[6] Thunderhead Engineering, "Pathfinder - Technical Reference." 2018.

[7] D. C. Duives, W. Daamen, and S. P. Hoogendoorn, “State-of-the-art crowd motion simulation models,” *Transp. Res. Part C*, vol. 37, pp. 193–209, 2013.

[8] I. Cilenti, “Crowd evacuation in high-density scenarios,” Lund University, Lund, Sweden, International Master of Fire Safety Engineering (IMFSE) Report 5590, 2019.