Collective Dynamics

Analyzing the Effects of a Column in front of a Bottleneck in a Transportation Infrastructure using Real-World Trajectories

Thomas Matyus[1] · **Martin Stubenschrott**[1] · **Stefan Seer**[1] · **Christian Kogler**[1]

[1] Austrian Institute of Technology (AIT),Vienna, Austria,
E-mail: thomas.matyus@ait.ac.at

Received: 2 November 2023 / Last revision received: 18 April 2024 / Accepted: 6 June 2024
DOI: 10.17815/CD.2024.182

Abstract In this paper, the effects of placing a column in front of a bottleneck in a real environment under everyday conditions are investigated regarding to person densities, pedestrian flows and personal distances. The study area is a transport infrastructure in Vienna with an attached shopping mall and the column was positioned at various locations in front of the entrance of the shopping mall. For the data analysis, the person trajectories of several scenarios were recorded using video-based sensors. In the scenarios with the column, the densities in front of the bottleneck increased but flows got a nuance smoother with less stop-and-go movements.

Keywords Real-world experiments · real-world data · interventions · transport infrastructure · pedestrian movement

1 Introduction

Nowadays many public infrastructures are confronted with the problem of handling huge crowds. Hence, there is an urgent need to steer and control pedestrian flows efficiently. Especially, the flows at bottlenecks like doors and passages have to be optimized with respect to performance, safety and comfort. A long list of experiments have been carried out under laboratory conditions ([1], [2], [3]) or in virtual environments ([4]) to understand pedestrian flow characteristics through bottlenecks up to a width of 5m ([5]). The simulation study of [6] showed that the flow through a bottleneck increases when a column is positioned in front of it. The experiments described in [7] confirm this hypothesis, others (an overview can in be found in [8]) at least partially.

The above mentioned studies focus on the evacuation case with high person densities and with uni-directional flows through the bottlenecks. In contrast, we investigated whether bi-directional flows with varying (low to medium) densities through a wide (3.9m) bottleneck in every day situations can be influenced by simple structural modifications. For this purpose, five scenarios have been defined where a column was positioned at different locations and with different designs in front of the entrance to a shopping mall. Furthermore, the studies have been carried out under laboratory conditions, whereas the investigations in this work are based on real-world data.

In the following sections we describe the whole process of data aqusisiton, pre-processing and analyzing of real-world trajectory data recorded in a transportion hub in Vienna.

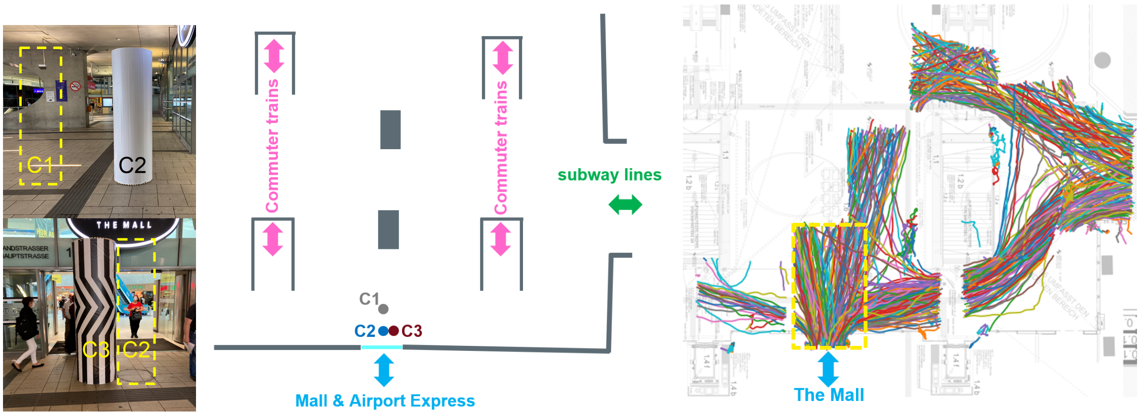
2 Data aquisition

A railway station in the center of Vienna (Austria) was chosen as the observation area, which is directly connected to a shopping mall (see Fig. 1(a)). The site is a public transport hub with two subway lines, commuter trains and airport express train, which is characterized by a mixture of people knowing the infrastructure and of those who are here for the first time. In [9] it has already been investigated how pedestrian flows can be influenced by interventions in a real environment. There, video-based sensors, among others, were used for data recording, which were also used in our investigations.

2.1 Data Recording and Interventions

At the ceiling in front of the door of the station, at the transition from the station to the mall eight video-based counting sensors were mounted also covering the doorway. These sensor types were able to directly extract the trajectory data from the video footage and could be merged to a unified view. This makes it possible to track the paths of pedestrians across neighboring sensor areas. However, data precision is significantly reduced at the boundaries of two areas. An example view of recorded trajectories can be seen in Fig. 1(b).

In order to investigate the impact of an obstacle on pedestrian flows directly in front of a bottleneck, a column (70cm diameter, 250cm height) was set up at three different positions (see Fig. 1(a) and (b)). Additionally, the initially white cover of the column was replaced with an arrow design (see Fig. 1(a)), in order to see if this would stimulate more people to pass the column on the right. In total, five scenarios were defined: 1) base scenario without any changes in the study area, 2) a white column placed centrally in front of the exit at a distance of 3.8m (position C1 in Fig. 1(a) and (b)), 3) a white column centrally at a distance of 1.6m (position C2 in Fig. 1(a) and (b)), 4) the same column position as in scenario 3 but with arrow design and 5) column with arrow design moved 70cm to the right from the previous position (position C3 in Fig. 1(a) and (b)).



(a) (b) (c)

Figure 1 (a) The upper picture shows the column with the white cover at positions C1 and C2, the lower one shows the column with the arrow cover at positions C2 and C3. (b) Overview of the investigation site with the directions to the public transport lines and the entrance of the mall. The three column positions are marked with C1, C2 and C3. (b) Example view of recorded trajectories

2.2 Data Pre-processing

For the analysis, the recorded trajectories of a whole day (06.00h – 21.00h) were evaluated. In order to get comparable results those days with similar numbers of trajectories were selected: “Base” 54k, “C1” 58k, “C2” 53k, “C2 with Arrows” 55k and “C3 with Arrows” 61k. In a first step the data have been resampled with 10Hz and then smoothed by applying the Savitzky-Golay filtering (see [10]). In order to minimize data errors (see Sec. 2.1) trajectories are clipped to a 3.9m x 5m rectangular zone in front of the entrance to the mall (see Fig. 1(b)) which is covered by a single sensor.

2.3 Data Analysis Methods

In several works in which pedestrian data were analyzed [eg. [11]), the focus lies on determining the kinematic quantities and the fundamental diagrams. Here we want to focus more on macroscopic variables in order to be able to better understand the influence of the interventions: 1) Determining the main flows, 2) computing the Voronoi densities, 3) determining the distribution of the minimal personal distances, 4) calculating the travel speeds and 5) the percentage of trajectories with delays.

To determine the main flows, the trajectories were clustered by start and end points. For the direction into the mall, six start zones were defined - in clockwise order (see Fig. 2(a)): left-down, left-up, center-left, center-right, right-up, right-down. For the outflows two start zones (left-out and right-out) and three target zones (left, center and right) were defined (see Fig. 2(b)). In the second step, the spatial average trajectories were determined for each cluster.

The work of [12] has shown that determining the person density using Voronoi diagrams is a reasonable method for video-based trajectories. To better visualize the com-

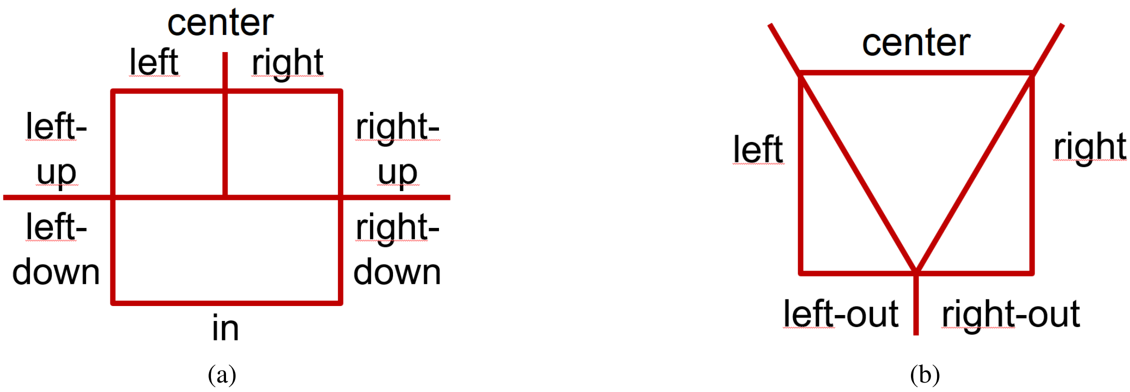


Figure 2 Scheme for clustering the flows (a) into the mall and (b) out of the mall.

parison between scenarios, the Voronoi densities were mapped onto a 50cm x 50cm grid. For each cell of the grid, the difference between the density values of two scenarios were calculated and color-coded. Additionally, we calculated the minimal personal distances. For this purpose, we determined for each person the minimum distance he or she had to another person in the course of his or her path through the evaluation zone.

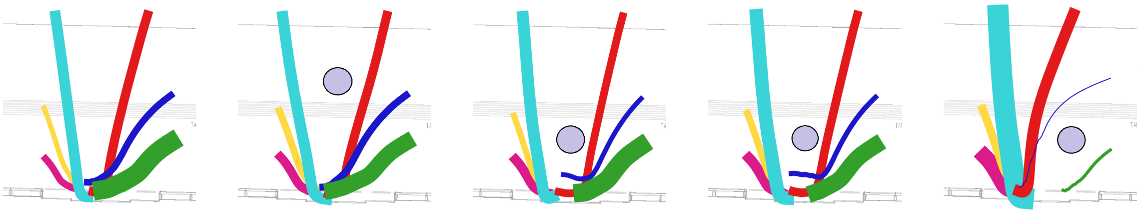
For the analysis of travel speeds, only those trajectories were used whose start and end points lie outside the evaluation area. The average walking speed was then calculated as the quotient of the walked distance within the evaluation zone divided by the time required for the walk. As a further indicator, the percentage of trajectories with delays have been computed: Counting the events when walking speed drops below 0.4 m/s in relation to the number of trajectories.

3 Results

Beginning with the main flows of the flows into the mall, there are no obvious differences for the first four scenarios (see Fig. 3(a) - d). However, moving the column to position C3 leads to a shift of the flow coming from the upper right corner. The corresponding main flow now leads around the column to the right (see Fig. 3(e)). For the flows out of the mall, only scenario “C3 with Arrows” shows significant changes (see Fig. 4). Both, the right outflow up to the center and the crossing flow from left to right passes the column now on the left side (see Fig. 4(e)).

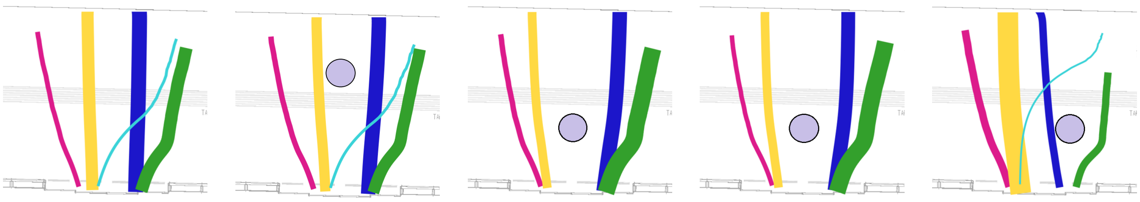
In all column scenarios, it can be seen in Fig. 5, that the placement of the column has increased the Voronoi densities in the cells close to the bottleneck and the maximum density values (see Tab. 1) compared to the base scenario. This is reflected in the results of the minimal personal distances. The minimum distances between persons are reduced in the case of the column scenarios (see Tab. 1).

While travel speeds are slightly reduced in column scenarios (see Tab. 1), there is an indication that flows have become a little more fluid. All column scenarios show a significantly lower percentage of delays (see Tab. 1).



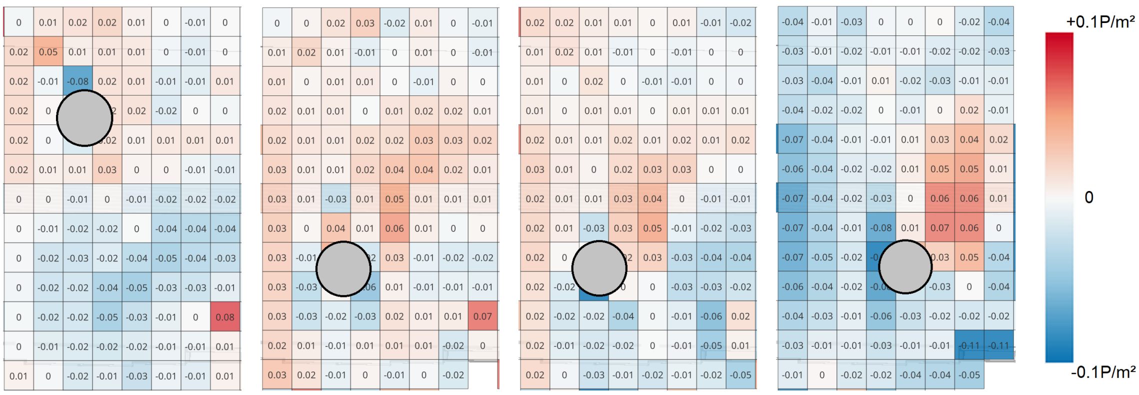
(a) (b) (c) (d) (e)

Figure 3 Main inflows in (a) the base scenario, (b) scenario C1, (c) scenario C2, (d) scenario C2 with Arrows and (e) scenario C3 with Arrows



(a) (b) (c) (d) (e)

Figure 4 Main outflows in (a) the base scenario, (b) scenario C1, (c) scenario C2, (d) scenario C2 with Arrows and (e) scenario C3 with Arrows



(a) (b) (c) (d)

Figure 5 Differences of the Voronoi densities [P/m²] for (a) scenario C1 (b) scenario C2, (c) scenario C2 with Arrows and (d) scenario C3 with Arrows versus the base scenario. A red cell color indicates a positive difference (density in base scenario is smaller), blue a negative difference (density in base scenario is higher). The color intensity corresponds to the value of the difference.

scenario	Max. Densities [P/m²]	Personal Distances median [cm]	mean [cm]	stddev [cm]	Travel Speeds mean [m/s]	stddev [m/s]	Delay [%]
Base	0.29	78.4	89.9	40.4	1.13	0.32	14.5
C1	0.35	75.6	83.9	38.2	1.11	0.31	11.0
C2	0.39	74.8	83.9	40.0	1.10	0.31	12.1
C2 wA	0.39	73.9	82.3	39.3	1.10	0.31	11.4
C3 wA	0.38	72.9	81.2	41.7	1.10	0.31	11.0

Table 1 Maximum person densities, minimal personal distances, travel speeds and percentage of delays for each scenario.

4 Discussion

In this paper we described the whole process of data aqusisiton, pre-processing and analyzing real-world trajectory data recorded in a tranport infrastructure for different scenarios where a column was positioned at different locations in front of an entrance to a shopping mall. In general, the chosen analysis methods are able to describe the phenomena of the different scenarios and they revealed that the column (independent from its position) has a slightly negative effect on the travel speed and densities but makes flows a nuance smoother with less stop-and-go movements.

Nevertheless a lot of discussion points arise. Since the five scenarios were implemented on different days, the question arises to what extent the data sets and the boundary conditions are really comparable. Would additional analysis methods e.g. measuring the disentanglement of the flows lead to new findings? And of course, what are the impacts on the simulation models: Can state-of-the-art models reproduce the results? Are model adaptions necessary? Have the operative models to be touched or the tactical or both?

Acknowledgements This research was conducted as part of the research project perceiving:spaces, which aimed to test the possibilities of influencing pedestrian flows in real-world experiments. The project was funded by the Österreichische Forschungsförderungsgesellschaft mbH (FFG): project 869875, research programme "Beyond Europe". Special thanks to the project partners: BRIMATECH Services GmbH, Carlo Ratti Associati SRL (CRA), Senseable City Lab at the Massachusetts Institute of Technology (MIT), ÖBB-Immobilienmanagement GmbH.

Ethics Statement The data aquisition was carried out in compliance with all provisions of the General Data Protection Regulation, which came into force in Austria on May 25, 2018, and in coordination with the infrastructure operators.

Author Contributions Thomas Matyus: Writing – original draft, Visualization / Martin Stubenschrott: Data curation, Writing – review and editing / Stefan Seer: Conceptualization, Supervision, Writing – review and editing / Christian Kogler: Project administration, Writing – review and editing.

References

[1] Hoogendoorn, S., Daamen, W.: Pedestrian behavior at bottlenecks. Transp. Sci. **39**, 147–159 (2005). doi:0.1287/trsc.1040.0102

[2] Seyfried, A., Passon, O., Steffen, B., Boltes, M., Rupprecht, T., Klingsch, W.: New insights into pedestrian flow through bottlenecks. Transp. Sci. p. 395–406 (2009). doi:10.1287/trsc.1090.0263

[3] Garcimartín, A., I., Z., Pastor, J., Martín-Gómez, C., Parisi, D.: Experimental evidence of the 'faster is slower' effect. Transp. Res. Procedia **2**, 760–767 (2014). doi:10.1016/j.trpro.2014.09.085

[4] Ronchi, E., Nilsson, D., Kojić, S., et al.: A virtual reality experiment on flashing lights at emergency exit portals for road tunnel evacuation. Fire Technol. **52**, 623ff (2016)

[5] Liao, W., Seyfried, A., Zhang, J., Boltes, M., Zheng, X., Zhao, Y.: Experimental study on pedestrian flow through wide bottleneck. Transportation Research Procedia **2**, 26–33 (2014). doi:10.1016/j.trpro.2014.09.005. The Conference on Pedestrian and Evacuation Dynamics 2014 (PED 2014), 22-24 October 2014, Delft, The Netherlands

[6] Helbing, D., Farkas, I., Molnar, P., Vicsek, T.: Simulation of pedestrian crowds in normal and evacuation situations. In: Schreckenberg, M., Sharma, S.D. (eds.) Pedestrian and Evacuation Dynamics, vol. 21, p. 21–58. Springer (2002)

[7] Yanagisawa, D., et al.: Introduction of frictional and turning function for pedestrian outflow with an obstacle. Phys. Rev. E **80** (2009). doi:10.1103/PhysRevE.80.036110

[8] Shiwakoti, N., Shi, X., Ye, Z.: A review on the performance of an obstacle near an exit on pedestrian crowd evacuation. Safety Science **113** (2019)

[9] Corbetta, A., Kroneman, W., Donners, M., Haans, A., Ross, P., Trouwborst, M., Van de Wijdeven, S., Hultermans, M., Sekulovski, D., van der Heijden, F., et al.: A large-scale real-life crowd steering experiment via arrow-like stimuli. Collective Dynamics **5**, 61–68 (2018)

[10] Savitzky, A., Golay, M.: Smoothing and differentiation of data by simplified least squares procedures. Analytical Chemistry **36** **(8)**, 1627–39 (1964). doi:10.1021/ac60214a047

[11] Corbetta, A., Bruno, L., Muntean, A., Toschi, F.: High statistics measurements of pedestrian dynamics. Transportation Research Procedia **2**, 96–104 (2014). doi:10.1016/j.trpro.2014.09.013. The Conference on Pedestrian and Evacuation Dynamics 2014 (PED 2014), 22-24 October 2014, Delft, The Netherlands

[12] Steffen, B., Seyfried, A.: Methods for measuring pedestrian density, flow, speed and direction with minimal scatter. Physica A **389**, 1902–1910 (2010). doi:10.1016/j.physa.2009.12.015