Calibrating a General Pedestrian Stream Simulation Model According to a Specific Real Life Scenario of a German Railway Station

M. Davidich and G. Köster

Abstract Pedestrian stream simulations are used to mitigate risks for people in buildings and at public events. They allow gaining virtual experience for situations where it is impossible to gather real experience. At some point even short term predictions may become possible. However, simulations remain useless if the simulation tool does not reliably reproduce the true phenomena. Hence, one of the biggest challenges in the applied research field of crowd motion is the validation of the proposed models. Up to now very little data from real-life scenarios has been available and calibration attempts have mostly relied on literature values or, at best, laboratory measurements. Instead, we propose to extract key data from live video records as a part of a methodological approach that makes possible to calibrate a simulation tool against video data. We re-enact a real-life scenario observed at a major German railway station with a benchmark simulator and compare the results to the video observations to give a proof of concept for our approach.

Keywords Pedestrian simulation • Cellular automata • Real-life scenario • Validation

1 Introduction

Pedestrian stream simulations have become an integral part of planning public buildings and large events [1–7, 10]. They are seen as means to mitigate risk for life and limb of people visiting buildings or attending public mass events. Their

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U. Weidmann et al. (eds.), *Pedestrian and Evacuation Dynamics 2012*,
DOI 10.1007/978-3-319-02447-9_53,

strength lies in the number of scenarios that their user can virtually enact to gather insight, in cases when it would be uneconomical, unethical or simply impossible to gain real experience.

Another, yet largely unachieved goal is to produce short time predictions from real-time simulations. A time frame of only 3 min may be sufficient to act in many cases, e.g. when a station manager is faced with the decision, whether to allow a full train into an already full station. In real-time simulations of pedestrian behaviour live data is collected and a simulator is calibrated against the actual scenario. Geometry, occupation and even fundamental diagrams are used as input to enable predictions on the evolution of the scenario. But how do we know whether the prediction is trustworthy? When we re-enact a real-life scenario in a computer simulation, we expect that at least the important characteristics of the scenario are reproduced. Unfortunately most calibration attempts are still based on literature data or laboratory experiments that remain to some extent artificial and deal with isolated phenomena. Extracting data from the real-life observations is necessary to gather evidence that a complete scenario with its more varied aspects will be also reliably reproduced [8, 13–18].

In this paper we present a holistic approach to solving this problem: We gather video data through video cameras (in our example installed at a German railway station) and then combine data collection, data analysis and calibration of simulation against data from live scenario to ensure high quality predictions of pedestrian flows. In particular, we look at the free-flow velocities of pedestrians and the fundamental diagram and discuss their deviation from the classic literature values on density-flow relationships compiled in [19]. The proposed methodology is then applied to one of our sample videos. We then re-enact the scenario in a benchmark simulator and compare the evolution of the density of the simulation experiment to the performed measurements in several observation areas.

2 Gathering Data for the Scenario: A German Railway Station

We used partly automated video tracking to estimate pedestrian paths, walking speeds, schedules of appearance and disappearance of pedestrians. The examined area includes several platforms and a part of the station's main hall (Fig. 1). All data is anonymous: A single person has the size of a few pixels. We analyzed two video recordings, each of it is about 1.5 min long with about 400 paths on each video. Some trajectory parts are obscured by obstacles or far off. The obscured and distorted trajectories were excluded from the analysis. Detailed analysis of the velocity distribution and deceleration of pedestrians with increasing density was restricted to fully visible and undistorted parts. A schematic view of the experiment is shown in Fig. 1.

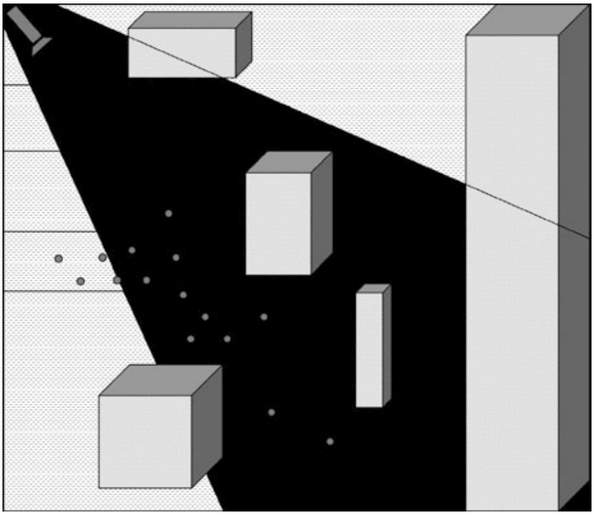

Fig. 1 Schematic representation of a video measurement: The *black area* corresponds to the examined area, the position of a camera is schematically shown at the *left corner*. The platforms are represented with *lines* and are on the *left part* of the scenario. The *grey parallelepipeds* correspond to the obstacles. The *grey points* are the schematic representation of pedestrian positions

3 The Benchmark Simulation Tool

As a benchmark simulation we use a simulation based on cellular automation. We choose the cellular automation approach for its simplicity and speed, especially for large scenarios with thousands of persons and difficult topology. The detailed description of our simulation can be found in [20, 21]. Here, we describe the main ideas of the model.

The whole simulation area is covered with cells. Each cell has two states: it is either empty or occupied. It can be occupied by a person, an obstacle or a source or a target. The source denotes a place from where pedestrians enter a scenario, and a target denotes pedestrian destinations. The cells have a hexagonal shape that allows pedestrians to move in six different directions. The cell size is 53 cm, which corresponds to the average shoulder width of European males.

To each pedestrian a combination of potentials is applied (Fig. 2):

– A target potential, i.e. a person tries to achieve its destination/target.
– Repulsive forces of obstacles.
– Repulsive forces of other pedestrians.

These potentials are added to receive a resulting potential for each cell at each time step. Each virtual pedestrian tries to get to his or her destination and moves in accordance with a sequential update scheme, which makes collisions impossible. The speed of motion depends on the individual pedestrian speed, i.e. the speed when the path in the direction of movement is free. If there are other people present in the direction of movement, pedestrians have to decelerate.

A lot of attention was paid to the calibration of the model. A detailed description can be found in [21].

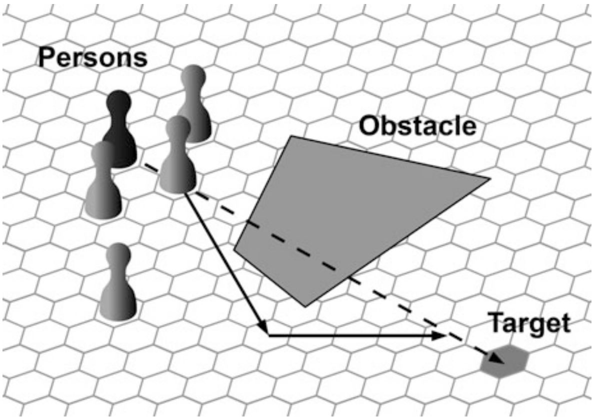

Fig. 2 Pedestrians move on a grid with hexagonal cells towards a target. Persons, targets and obstacles occupy cells. Positions are updated sequentially in each simulation step, so that collision is impossible

4 Realistic Calibration According to Video Data

In order to adjust a simulation to a certain real life scenario, as a first step, a set of relevant parameters should be selected, that capture the most vital phenomena.

4.1 Free-Flow Velocity

It is often assumed that the distribution of pedestrian free-velocities has a Gaussian form, and that the average velocity is 1.34 m/s with a standard deviation of 0.26 m/s. The extracted data from the video footage of the railway station scenarios also suggests a normal distribution of the velocities. However, the measured velocities deviate from the standard 1.34 m/s value. The pedestrians at the railway station tend to walk slower, with an average velocity of 1.04 m/s and a standard deviation of 0.51 m/s. All results are shown for video recordings which were taken in the late afternoon at around 5.30 p.m. on a working weekday.

4.2 Flow-Density Dependence

Pedestrians tend to decelerate as density increases. When no additional information is available, it is often assumed that pedestrians decelerate in accordance with the Weidmann's fundamental diagram [19]. However, recent investigations show that deceleration can vary and depends on many factors such as, for example, nationality [22]. Information on how pedestrians decelerate is necessary to reproduce a scenario in a simulation. It is crucial especially for critical scenarios in which high densities and inability of pedestrians to move may lead to a disaster.

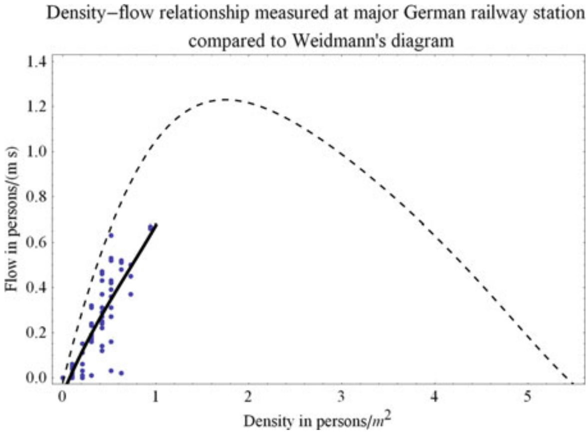

Fig. 3 Measured density-flow relationship at the German railway station compared to Weimann's diagram (*dashed line*). *Dots* are the measured values of flow for a certain density. The maximum difference in flow between Weidmann's data (already given in a smooth form) and the measured data is 0.4 persons/ms. Densities above 1 person/m^2 did not occur. The *solid line* is a smooth approximation of the measured data

Our measurements taken at the station show that pedestrians decelerate differently than one would expect based on Weidmann's diagram. Again, the analyzed video recordings were taken during a working day at around 5.30 p.m. The results are shown in Fig. 3: The pedestrians decelerate stronger than in Weidmann's fundamental diagram. The algorithm used to calibrate our simulation model against measured flow-density diagrams is described in detail in [21].

4.3 Schedule of Pedestrians Entering and Leaving of the Scenario

The schedule of pedestrians entering and leaving is usually individual for every specific scenario. It is necessary to insert virtual pedestrians into the simulation so that it fits the scenario and to adequately remove them from the simulation.

Apart from the parameters mentioned above and the schedule of pedestrian entering and leaving of the scenario, statistical information on the distribution of trajectories and information on topology must be included into the calibration:

5 Comparison of Measured Data to Simulation Results

Once the steps described in the calibration section are completed, a comparative simulation can be started. In our case we conducted the statistical analysis described above and constructed a fundamental diagram that fits the measured data. The scenario we re-enact was recorded during the rush hour in the afternoon. A train arrives on a platform (on the left side of Fig. 4), passengers exit the train and move to different destinations to the subway entrances, food stalls, elevators and other

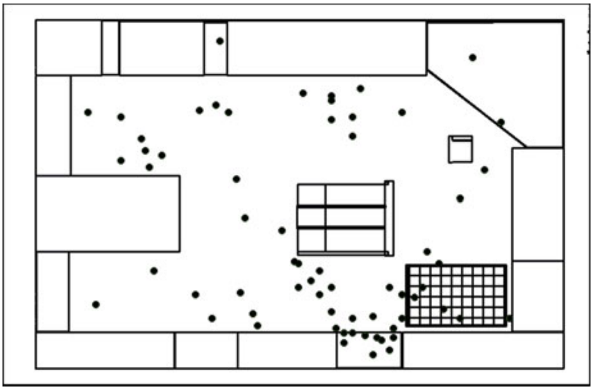

Fig. 4 Snapshot of a simulated scenario. *Circles* correspond to pedestrians. *Lines* represent contours of obstacles and source and target location. The *rectangle* covered by a *grid* shows the area of observation

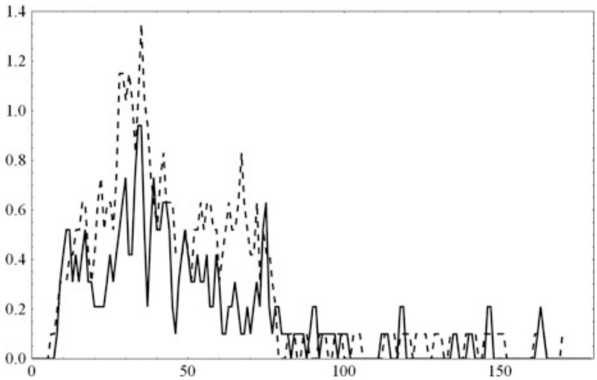

Fig. 5 Comparison of measured densities from video footage (*solid line*) simulated densities (*dashed lines*) when pedestrians are inserted into the scenario with the source/target distribution, free-flow velocities and the density-flow relationship measured at the start of the scenario. 180 s (3 min) are simulated

platforms. Clearly, the density is low at first. When the bulk of the crowd appears, a higher pedestrian density is measured for 3 min; afterwards no more passengers come from the platform. The density goes down again.

Figure 5 shows a comparison of simulated to measured densities in a time span of 3 min. Solid lines correspond to the video footage, dashed lines to the simulation. The peak density occurs in the proper area of observation, at the correct time, for the correct duration and in the correct order of magnitude, but is some-what higher than in reality. This can be partially explained by the influence of random choices in the simulation regarding velocities of the virtual pedestrians and their destinations: Only the distributions of the input and measurement parameters coincide. We also suspect that the real pedestrians coordinate their movements better than the virtual pedestrians. The virtual pedestrians are quite 'short sighted' and take steps to avoid collision only when they actually 'feel' the potential of other pedestrians. Real pedestrians are more likely to plan ahead. This is a typical disadvantage of high speed pedestrian stream simulators that need to restrict influences to the near field, so-called greedy algorithms, to keep computation times low.

The question is whether this systematic overestimation is acceptable. If we are interested in a warning system for potentially dangerous densities, than a slight overestimation can be tolerated, whereas underestimations would be unacceptable.

6 Discussion and Next Steps

In this paper, we analyzed video data gathered from the complex real-life scenario at the major German railway station and calibrated a benchmark simulation tool according to the measured data. The density evolution of the simulated data well matches the measured data in the area of observation. In that sense, the paper constitutes a proof of concept. Short term predictions of crowd densities are therefore possible, within a certain range of applications, if one carefully adjusts the input parameters to the measured parameters.

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