The simulation of crowds at very large events

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Summary. In this article, we show tow examples for the application of pedestrian flow simulation and analysis: the World Youth Day 2005 in Cologne and the egress (non-emergency) from a football stadium. Various circumstances are specific for religious events. The persons might perform rituals and therefore the pat-terns of movement or gathering are governed by rules that go beyond simple necessity or comfort. Furthermore, the persons are usually very much attracted by the (idealistic) aim of their pilgrimage. The final service at the World Youth Day 2005 in Cologne, celebrated by the Pope, was the major event dur-ing the WYD. The paper is divided into thre parts: The first section is con-cerned with the World Youth Day and the second with the egress from a foot-ball stadium. The final section summarizes the results, provides recommenda-tions and concludes with the most important implications for the field of crowd dynamics simulation.
Keywords: crowd movement, simulation, egress, evacuation, cellular automata, pedestrian dynamics

1 Description of the Model

1.1 Model Characteristics

The model is extensively described in Klüpfel et al. [2000], Klüpfel [2003], Meyer-König et al. [2001]. It is similar to the model used in Kirchner et al. [2002, 2004] to simulate competitive egress behavior apart from the friction and the dynamic floor field. The model characteristics can be summarized as follows:

1. The geometry is respresented as a regular grid of quadratic cells where walls are represented as non-accessible cells. The cell size is 40cm.
2. Persons move on these cells. Their velocity may vary between 2 and 5 cells per time step. The length of a time step is 1 second.
3. Diagonal movement is possible and the diagonal distance is correctly accounted for (by a factor of $\sqrt{2}$).
4. The update is shuffled sequential Wölki et al. [2006], which is equivalent to an iterative conflict resolution Kirchner et al. [2004].

5. There are as many static potentials (called floor fields in Burstedde et al. [2001], Kirchner et al. [2002, 2004] as there are exits. Each potential measures the distance to its exit.
6. There is no dynamic floor field.
7. The transition probabilities are given by $e^{\Delta p}$, where Δp is the difference between the potential of the current and the destination cell. The exit has potential 0.

1.2 Parameter Settings

The following table 1 contains the parameter values for the standard population used in the examples in sections 2 and 3. It is important to note that the reaction time distribution was deliberately choosend to be very low in order to get a worst case scenario. It is well known from empirical observations Purser and Bensilium [2001] that immediate detection of and reaction to an alarm leads to the highest rates of congestion.

Parameter	Minimum	Maximum	Mean	Std. Dev.	Unit
Free Walking Speed	2	5	3	1	m/s
Dawdling Probability	0	0.3	0.15	0.05	-
Reaction Time	0	10	5	2	s

Table 1. Parameters of the standard population.

2 World Youth Day

The World Youth Day took place in August in Cologne, Germany. The final event was a service with Pope Benedict XVI. It was held on a large ground (around 92 ha) with a stage in the centre. The geometry is shown in fig. 1. Altogether around 700 to 800 thousand pilgrims were expected. Apart from the roads and public transportation systems, the footpaths played of course also an eminent role in the mobility concept.

Concerning pedestrian motion, two cases must be distinguished: the normal case of getting to and back from the area and the emergency case, when part of the site or the complete area has to be evacuated. In order to estimate the performance of the roads and footpaths in case of an emergency evacuation, several simulations were performed. One example is shown below. Since the size of the are is about 2km in East-West and about 1.6 km in North-South direction, a complete evacuation is in most cases neither sensible nor feasible. The scenarios considered were accidents with trucks or a fire. In these cases, the strategy was to evacuate the field directly affected and one neighbouring field (the rectangular areas defined by the roads and footpaths - cf. 1).

The scenario shown in fig. 2 is a fire on or near the central stage and a partial evacuation of the so called pilgrim near the location of the incident. After 30 minutes

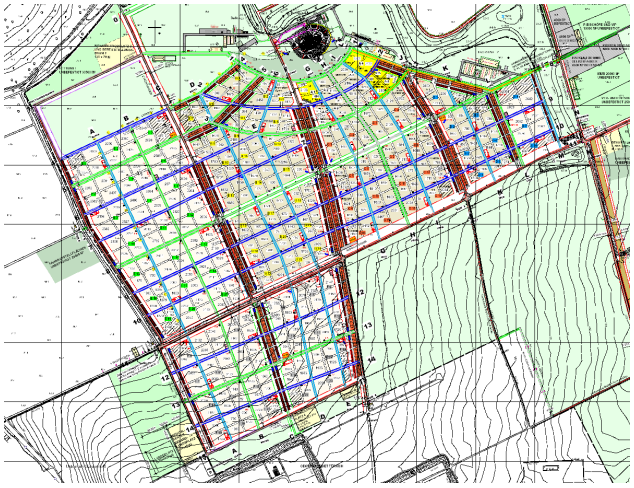

Fig. 1. World Youth Day Premises: The ”Marienfeld” near Kerpen and Cologne.

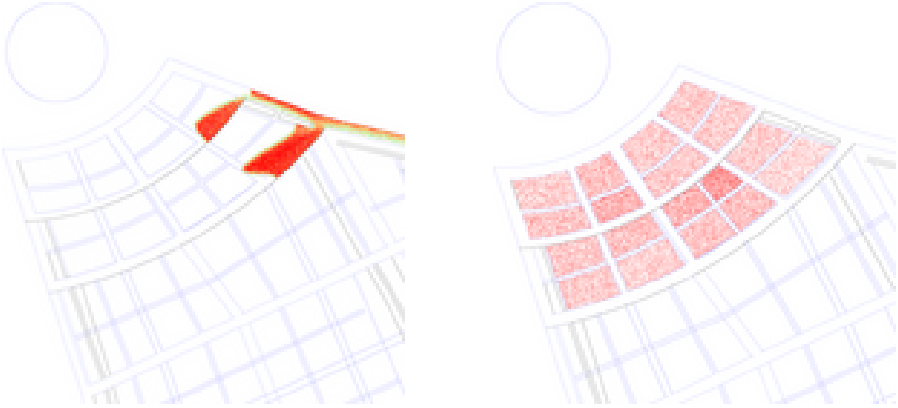

Fig. 2. World Youth Day Simulation: Initial Distribution of 36,000 persons for the scenario ”fire near the stage”. The area is 32,000 sqm, i.e. 32 ha and the density ca. 1.1 persons/sqm.

the major part of the afflicted area can be evacuated. However, it takes another one and a half hours to get the persons completely off the area in this simulation. Since the surrounding pilgrim fields are also filled with people, there is a strong need to contain the thread within a few fields (the small rectangles defined by the paths and roads - cf. fig. 1). Otherwise the complete area would have to be evacuated which took more than 4 hours in the simulation. There was, however, open space several times larger than the ”Marienfeld” around the area which is a necessary condition for the being able to evacuate in the first place.

3 Egress from a Football Stadium

Concerning quantitative verification, movement patterns provide a valuable tool to investigate the reliability of simulation results. In the following, video footage is compared to simulations, especially concerning overall egress time (non-emergency). The video footage was taken at an international match between Germany and Scotland in Dortmund (Westfalenstadion). The results described here are an extension of Klüpfel and Meyer-König [2003], where simulation results for the stands in the four corners of the stadium were investigated by simulations. This reference also contains further information on the model and its application. Furthermore, Klüpfel and Meyer-König [2003] contains an in depth description and comparison of different modeling approaches for pedestrian dynamics and especially evacuation simulation.

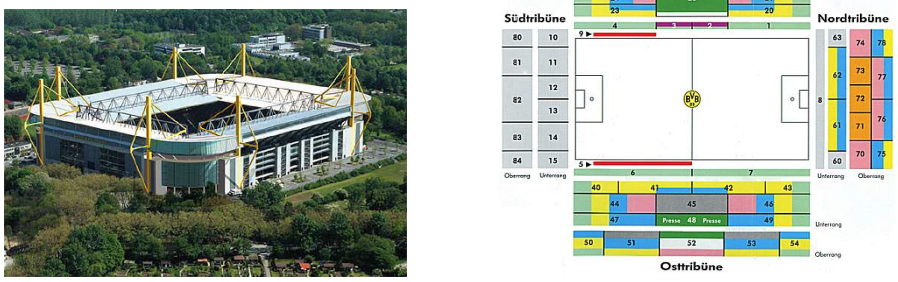

Fig. 3. The Westfalenstadion Dortmund: Outside view and general arrangement plan (Borusia Dortmund KGaA, www.borussia-dortmund.de.

In fig. 4 the first six minutes of the video footage and the first three minutes of the simulation are shown. The reason for the different time spans is that the real persons react slower. However, due to their effectivenes and group formation which is not represented in the simulation, the motion is more synchronized than in the simulation. Therefore, the snapshots were chosen such that the situations are comparable even though the times might be different.

For the second half of the egress shown in fig. 5 this difference vanishes and after 13 minutes, the situation is very much alike for reality and simulation. It is remarkable that after less than 15 minutes, the normal egress is nearly complete. One important pattern that can be identified is the sequence of egress from the rows. The lower rows are emptied first. This pattern is represented nicely by the simulation.

4 Conclusions

In this paper, two different events with very high numbers of pedestrians were presented. An important aspect in the egress from football stadiums is the V-like shapes

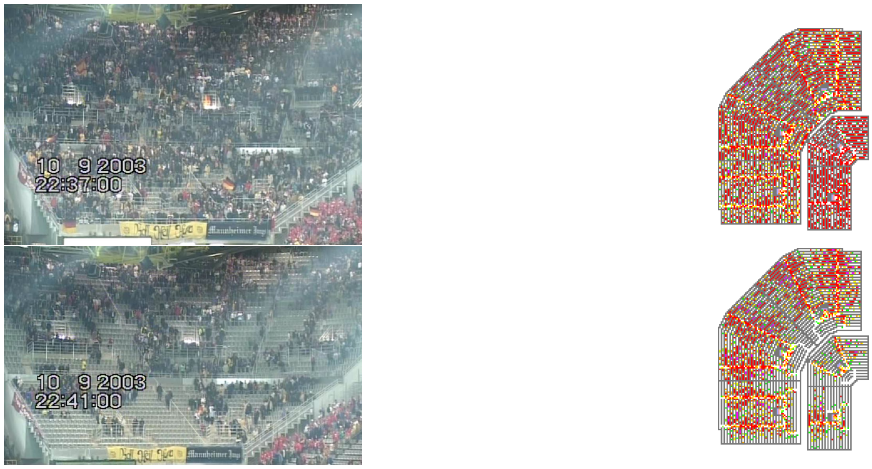

Fig. 4. The Westfalenstadion Dortmund: Comparison of the results for the video analysis (left column) and the simulation (right column) at the beginning of the egress. The video snapshots are taken at (from top to bottom) t=2 and t=6 minutes for the videos and t=20 seconds and t=3 minutes for the simulation.

Fig. 5. The Westfalenstadion Dortmund: Comparison of the results for the video analysis (left column) and the simulation (right column). The video (left column) and simulation snapshots (right column) are taken at (from top to bottom) t=10 minutes and t=13 minutes.

that are formed because the egress from the lower seating rows is faster. For events with several hundred thousand participants like the World Youth Day 2005 in and near Cologne (”Marienfeld”, Kerpen) an evacuation of the complete area is usually not advisable, as can be seen from the simulations presented and from the fact that the overall evacuatin time was estimated to be at least 4 hours.

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