Comparison of an Evacuation Exercise in a Primary School to Simulation Results

Hubert Klüpfel [a] Tim Meyer-König [b] Michael Schreckenberg [a]

[a] *Physik von Transport und Verkehr, Gerhard-Mercator-Universität, Duisburg, Germany*

[b] Traff*Go, Grabenstraße 132, 47057 Duisburg, Germany*

Abstract

The modeling of pedestrian movement has received growing interest over the last decades. This is due to the potential applications in facility design and especially evacuation simulation as well as the fascination of its fundamental properties. Empirical data plays a particular role with respect to both aspects. The key challenge in modeling and simulating crowd movement is to validate the model assumptions on the one hand and to verify the simulation results on the other hand. In this paper we present empirical data on an evacuation exercise in a primary school. About two hundred pupils (and their teachers) took part in the drill. Three drills were carried out. The premises are divided into two separate buildings, the larger one containing 6 classrooms with about 120 pupils. The results of the exercise are reported. Additionally, the time measured is compared to the time gained from a simulation. It took about 85 s to evacuate the whole school. It has to be noted that the result for the exercise is not a statistical one and no standard deviation can be given. The simulation estimated 160 s with parameter settings representing an average population. This deviation is mainly due to the fact that the students to not fit into this population demographics. We therefore adapted the parameters accordingly and got a result closer to the empirical one: (100 ± 4) s for the egress time (500 simulation runs), e.g., the empirical results is about $\mu_{\rm sim} - 3.8\,\sigma_{\rm sim}$.

Key words: Evacuation, Evacuation–Simulation, Evacuation–Exercise
PACS: 89.65.-s, 89.40.+k, 05.60.-k

Email addresses: `kluepfel@traffic.uni-duisburg.de` (Hubert Klüpfel), `m-k@traffgo.com` (Tim Meyer-König), `schreckenberg@traffic.uni-duisburg.de` (Michael Schreckenberg).

1 Modeling and Simulating Evacuation Processes

Pedestrian dynamics is a vital and growing interdisciplinary field of research [2,4]. Especially the subject of evacuation simulation has attracted increasing interest. Overviews over the different simulation and optimization methods available can be found in [6–8]. They can be roughly classified into:

(1) regression models (hydraulic/hydrodynamic),
(2) queuing models,
(3) route-choice models (mesoscopic),
(4) macroscopic models and gas-kinetic models (differential equations), and
(5) microscopic models (social force model) [9] and Cellular-Automaton-Models (CA-Models) [10–13].

The purpose of this classification is the following: We will also compare the empirical data to simulation results in section 5. It depends to some extent on the modeling approach used, which data fits best to validate the model and to verify the assumptions the simulation is based on. For example, aggregated data, like flow density relationships or overall egress times can be used for all five types of approaches. However, in order to take into account individual behavior and differences between persons, one has to take a closer look. Then the data basis becomes scarce, since obtaining detailed data is harder than obtaining aggregated data.

The total evacuation time can be obtained by the following equation [14]:

$$t_{\text{evac}} = t_{\text{process}} + t_{\text{react}} + t_{\text{egress}} \tag{1}$$

2 Aspects influencing the evacuation exercise

The influences on an evacuation can be categorized as follows: configuration (e.g, geometry), procedure, environment (e.g., temperature) and behavior. The concrete influences in the case studied here are the following:

(1) Environment: no hazards, no aggravating circumstances (cf. section 4).
(2) Configuration: Escape route signs , familiarity with the building (see fig. 1 and section 3).
(3) Procedure: After the alarm signal is triggered, staff (teachers guiding students) and students start immediately leaving the buildings via the nearest exits.
(4) Behavior: Route choice is determined/known beforehand, walking speed is rather high (2–7 m/s), pausing for orientation is negligible.

It has to be kept in mind that a single exercise does not provide statistical data. There is no “true evacuation time” but a distribution of times. The results presented here constitute at most two measurements. It would usually be desirable to carry out a series of measurements which is not possible due to practical and time constraints (see table 1.3).

3 The evacuation exercise

The building consists of two separated parts. It houses a primary school with about 200 pupils. The geometrical details together with the initial distribution of the persons are shown in fig. 1. The initial distribution is taken from the statistical records of the headmaster (class sizes and rooms, not taking into account absences).

The procedure was the following:

(1) The alarm siren was triggered.
(2) The persons started evacuating.
(3) A person was considered evacuated when she reached the outside, e.g., had left the building via its main exit.

The cameras where placed in building 1 in the top left corner of the room right next to the main exit on the ground floor (cf. fig. 1) and on the first floor at the door opposite to the staircase. This door was not used. In building 2 the one camera was placed beneath the stair leading from the ground to the first floor. The camera filming the main exit of building 1 was fixed on a tripod placed on a table, i.e., its position above ground was 2.20 m. All the other cameras where not mounted (handheld), so their position was about 1.80 m above ground.

Therefore all the videotapes show the doors from the inside which has the disadvantage that counting might be complicated by obstruction (persons walking directly behind each other). On the other hand, the queues forming in front of the doors can be observed. It would be desirable to have both views (inside and outside the door). This was not possible in this case, due to the restricted number of cameras available.

This procedure allows to obtain data that covers some of the individual behavior. However, it is not as detailed as to allow a direct and in depth comparison of, e.g., the trajectories of all the persons.

The number of persons was reconstructed from the videotapes in the way that the sum for each building is in accordance with the total count. Those numbers are lower than those provided by the headmaster of the school for the class sizes. The number of persons in each room (class) was not counted at the day of the exercise. The participants were all children of the age 6 to 10 (first to fourth grade). Demographic data can be taken into account in the simulation (cf. section 5) by

Fig. 1. Layout of the school building. It is separated into two independent parts (building 1 and 2), building 1 having three, building 2 two floors. The numbers show the initial number of persons in the rooms. The students gather on the playground just in front of each building.

the parameter settings. One aim of this endeavor was to determine (or at least get a feeling for) the appropriate parameter settings for such a population (cf. the next section).

4 Restrictions and Limitations

In addition to the restrictions mentioned, some further limitations have to be pointed out in order to avoid any misunderstanding. One could easily discrete the procedure by arguing that it is unrealistic. The special conditions are the following:

- The population was rather homogeneous. However, this has the advantage that its characteristics are known in detail.
- Population naturally divided into groups (classes) lead by a teacher.
- There were no hazards present.
- Fire brigade present.
- Students know scenario.
- Cameras visible.
- Several runs (see section 3).
- Whole procedure videotaped.

Therefore the results should be seen as representing an optimal case. Any deviation from those optimal conditions might change the outcome dramatically. It is not claimed that this exercise is realistic in the sense that it is close to what would happen in a real emergency. It is rather intended as a starting point for investigating the crowd dynamics under well defined circumstances and to provide information about the potential congestion areas and improvements. This is the nature of such an evacuation drill. And this is reflected in the simulation, too.

5 Results

Figure 2 shows the number of persons having left the building via the one exit on the ground floor vs. time (evacuation or egress curve) for building 1, fig. 3 for building 2. By taking the derivative of this curve, one can obtain the flow vs. time. The evaluation was done for building 1 and 2 separately. The exercise was done twice for building 2 and thrice for building 1. Due to the limited number of cameras results for all runs are available only for building 1.

The evaluation is based on the videotapes. In order to check the validity of the counting procedure, the procedure was repeated twice for building 2 (cf. fig. 3). It can be seen that there are small but tolerable deviations. The results are summarized in table 1.

Table 1
Times obtained from the evacuation exercise.

Building 1		Building 2	
first run			
1st out	10s	1st out	115 s
last from ground floor	37 s	last from 1st floor	35 s
1st from third floor	48 s	1st from 2nd floor	35 s
last out	77 s	last out	56 s
second run			
first out	4s		
last from 1st floor	39 s		
first from 2nd floor	47 s		
last out	81 s		
third run			
first out	11 s		
last out	67 s		

Surprisingly, drill 2 proceeded slightly slower than drill 1. The gap at 40–50 s (fig. 2) is between the first and second class on the first floor (due to the different behavior of the teachers: one moving in front of and the other behind the class (cf. fig. 1 for the floorplan and table 1 for the times). The shorter time for drill 3 is mainly caused by the fact that then the teacher of the second class was also moving behind the class, resulting in less congestion at the stair entry on the first floor, since the teacher moved slower than her class.

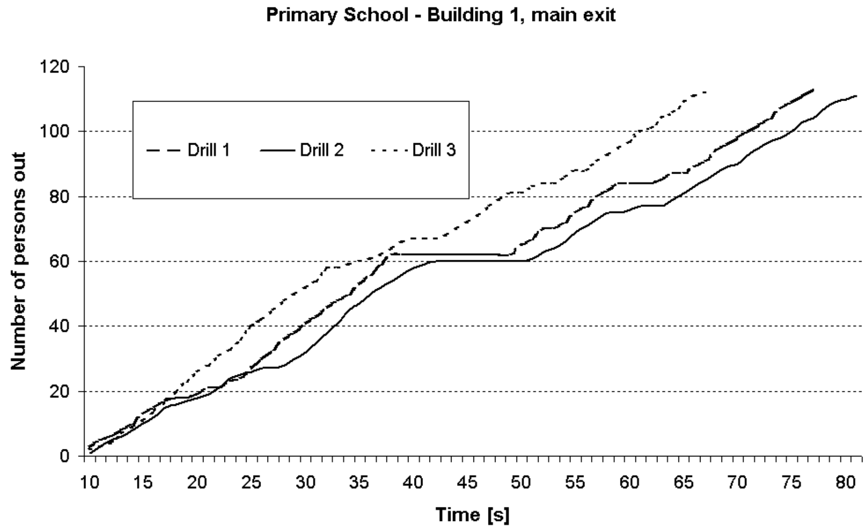

Fig. 2. Empirical egress curve (number of persons out vs. time) for building 1 (cf. fig. 1). Drill 1 to 3 are three different runs of the same scenario, with the same population and initial conditions. For explanation of the differences, see text.

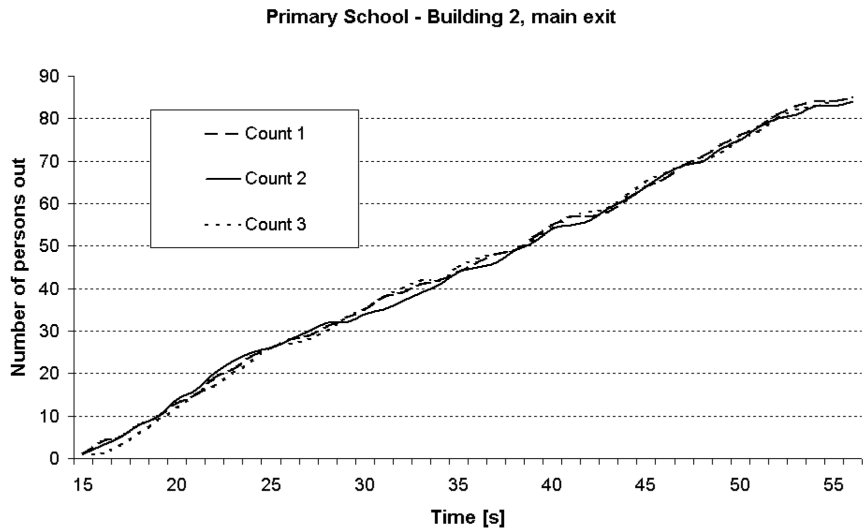

Fig. 3. Empirical evacuation curve: number of persons out vs. time for Building 2 (cf. fig. 1). Count 1 to 3 are based on the same film. Therefore the deviations are due to counting errors (see text).

In addition to the evaluation based on the experimental data, simulations were per-

Table 2
Parameter set used in the simulation. All distributions are Gaussian, μ is the mean value, σ the standard deviation. Since the space is discrete (0.4 m $\times$ 0.4 m quadratic cells), and the time step is one second, speeds are always multiples of 0.4 m/s.

Name	unit	Min	Max	μ	σ	comment
Average Population						
Maximum Speed	m/s	1.2	2.0	1.2	0.4	$\Delta v_{\max} = 0.4\ \mathrm{m/s}$
Reaction time	s	0	10	10	10	
Orientation frequency	%	0	25	10	10	probability for stopping
Swaying	%	1	6	4	1	prob. for directional dev.
Patience	s	100	100	100	50	has no influence
Adapted Parameters (Students)						
Speed	m/s	1.6	4.8	2.4	0.8	$\Delta v = 0.4\ \mathrm{m/s}$
Reaction time	s	0	10	5	2	
Orientation frequency	%	0	10	0	10	probability for stopping
Swaying	%	1	6	4	1	prob. for directional dev.
Patience	s	10	40	25	10	has no influence

formed. The simulation model is described in [10,15] (also available for download at `www.traffic.uni-duisburg.de/bypass/`, category publications). Psychological influences are neglected in the simulation. This is justified by the fact that the pupils are familiar with the surroundings and the egress proceeds orderly. In this case, the psychological influences are represented by the time for information processing t_{process} [16–18] and the reaction time t_{react} in eq. (1), which are both negligible here.

In contrast to the evacuation exercise, a simulation allows to do basically as many runs as one likes. Then, the statistical properties of the distribution of egress times can be investigated. The simulation results shown here are carried out based on the model described in [10]. Since the egress time for the school was determined by building 1, the simulation was restricted to this building. Figure 4 shows the distribution of egress times for building 1. The population parameters in the simulation were chosen as shown in table 2. Using a parameter set derived from the capabilites for an average population the simulation results deviated from the exercise. Therefore, the parameters were adapted and another simulation carried out. The parameter settings were based on the observations. E.g., the value for the parameter walking speed was derived from the time the first person left the building (see table 1 and figure 1).

The simulation results obtained using these parameters are shown in table 3 (for

Table 3
Simulated evacuation times (500 simulation runs).

Standard Parameters (Normal Population)	(160 ± 5.8)s
Adapted Parameters (Student Population)	(100 ± 4.0)s

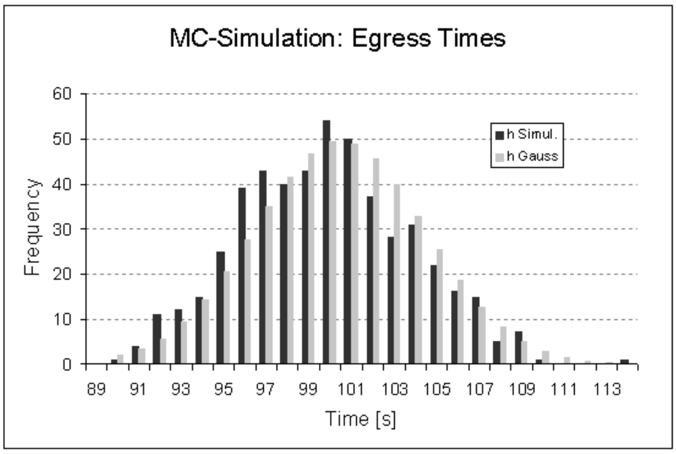

Fig. 4. Simulated egress times for building 1 (500 simulation runs). The parameters are shown in table 2 (adapted parameters for the student population).

500 simulation runs in each case).

Normal distributions were fitted to the distributions of egress times obtained by the simulations. In order to check the reliability of this approach, a χ^2-test was done [19]. The results are shown in table 4. χ^2 is defined as follows:

$$\chi^2 = \sum_{j=1}^{n} \frac{(h_j - n \cdot p_j)^2}{n \cdot p_j}, \tag{2}$$

where h_j is the frequency in the simulation, n is the number of simulation runs, and p_j is the Gaussian probability for the occurrence, e.g., $p_j = \Phi(c_j) - \Phi(c_{j-1})$, where $\Phi(x)$ is the probability density and c_i is the class boundary for class i.

The simulation run that corresponds to the median of the simulation times (fig. 4) was evaluated in detail. Figure 5 shows the simulated evacuation curve (the empirical one is shown in fig. 2), whereas fig. 6 shows the distribution of egress times in a single procedure, e.g. the frequency for the individual egress times. This data is only available for the simulation, since the students were not marked with numbers and could therefore not be identified individually.

Table 4
χ^2–Test for the simulation results for building 1.

Normal Parameters (Standard Population)		
k	32	number of classes
alpha	0,05	level of significance
1-alpha	0,95	level of certainty
χ^2	42.1	see eq. 2
$\chi^2_{32,0.05}$	46.2	quantile
$P(x^2 \geq \chi^2)$	0.11	error probability
Adapted Parameters (Student Population)		
k	26	number of classes
alpha	0,05	level of significance
1-alpha	0,95	level of certainty
χ^2	32.3	see equ. 2
$\chi^2_{26,0.05}$	38.9	quantile
$P(x^2 \geq \chi^2)$	0.18	error probability

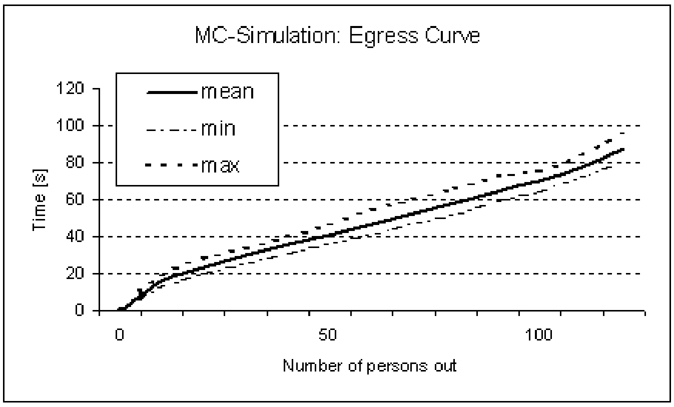

Fig. 5. Simulated evacuation curve for building 1 (500 simulation runs). The parameters are shown in table 2 (adapted parameters for the student population).

6 Summary and conclusion

We have reported results on an evacuation exercise performed in a primary school. The students were very familiar with the building, guided by their teachers, and highly motivated. The population is naturally divided into groups (classes). And the pupils are physically fit, probably even more than adults, very familiar with the building, and used to follow the advice of their teachers.

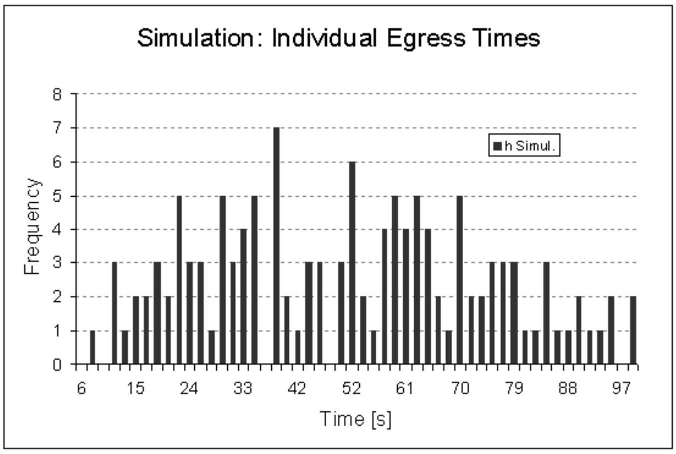

Fig. 6. Simulated egress times for building 1 (one simulation run). The parameters are shown in table 2 (adapted parameters for the student population).

Under these special circumstances, the evacuation proceeded very orderly and efficiently, the awareness and reaction were negligible, and the walking speed was rather high (up to 6 m/s). These factors have to be taken into account in an evacuation simulation in order to reproduce the observed behavior and evacuation times. In other terms: $p_{\mathrm{sway}} = p_{\mathrm{orient}} \approx 0$ (cf. table 1), e.g. there is no speed reduction due to orientation and no directional deviation (optimal route choice behavior). If a standard population is used in the simulation, the times obtained are too large by a factor 1.6.

Another remarkable result is the reduction of the evacuation time for a repeated drill, even though the motivation decreased. However, this influence was more than compensated by harmonization of the flow. Additionally, in the first drill the pupils were over-motivated and nervous.

Acknowledgment

We would like to thank the primary school in Duisburg Rahm, especially Mr. Tehbas, the caretaker and Mrs. Dommers, the headmistress, for their support, and last but not least all the kids. Our special thanks goes to Roland Chrobok for assisting us in videotaping the exercise. We are grateful to the German Ministry of Education and Research (bmb+f) for funding the BYPASS research project (Assessment and Analysis of Evacuation Processes on board Passenger Ships by Microscopic Simulation), the framework for conducting this research.

References

[1] S. Bandini and T. Worsch, editors. *Theoretical and Practical Issues on Cellular Automata*, London, 2000. Springer.

[2] M. Schreckenberg and S.D. Sharma, editors. *Pedestrian and Evacuation Dynamics (PED)*, Berlin, 2002. Springer.

[3] D. Canter, editor. *Fires and Human Behaviour*. David Fulton Publishers, London, 2nd edition, 1990.

[4] R.A. Smith and J.F. Dickie, editors. *Engineering for Crowd Safety*. Elsevier, Amsterdam, 1993.

[5] A. Di Nello, editor. *SFPE Handbook of Fire Protection Engineering*. National Fire Protection Association, 2nd edition, 1995.

[6] H.W. Hamacher and S.A. Tjandra. Mathematical modelling of evacuation problems – a state of the art. In Schreckenberg and Sharma [2], pages 227–266.

[7] Dirk Helbing, Illés Farkas, Peter Molnar, and Tamás Vicsek. Simulation of pedestrian crowds in normal and evacuation situations. In Schreckenberg and Sharma [2], pages 21–58.

[8] S.P. Hoogendoorn, P.H.L. Bovy, and W. Daamen. Microscopic pedestrian wayfinding and dynamics modelling. In Schreckenberg and Sharma [2], pages 123–154.

[9] Dirk Helbing, Illés Farkas, and Tamás Viscek. Freezing by heating in a driven mesoscopic system. *Phys. Rev. Lett.*, 84:1240–1243, 2000.

[10] H. Klüpfel, T. Meyer-König, J. Wahle, and M. Schreckenberg. Microscopic simulation of evacuation processes on passenger ships. In *Proc. Fourth Int. Conf. on Cellular Automata for Research and Industry*, pages 63–71, London, 2000. Springer.

[11] V.J. Blue and J.L. Adler. Cellular automata microsimulation for modeling bi-directional pedestrian walkways. *Transpn. Res. B*, 35:293–312, 2001.

[12] C. Burstedde, K. Klauck, A. Schadschneider, and J. Zittartz. Simulation of pedestrian dynamics using a 2-dimensional cellular automaton. *Physica A*, 295:507–525, 2001.

[13] J. Dijkstra, H.J.P. Timmermans, and A.J. Jessurun. A multi-agent cellular automata system for visualising simulated pedestrian activity. In Bandini and Worsch [1], pages 29–36.

[14] Ethel Graat, Cees Midden, and Paul Bockholts. Complex evacuation; effects of motivation level and slope of stairs on emergency egress time in a sports stadium. *Safety Science*, 31:127–141, 1999.

[15] T. Meyer-König, H. Klüpfel, and M. Schreckenberg. Assessment and analysis of evacuation processes on passenger ships by microscopic simulation. In Schreckenberg and Sharma [2], pages 297–302.

[16] G. Proulx. Evacuation time and movement in apartment buildings. *Fire Safety Journal*, 24:229–246, 1995.

[17] Peter G. Wood. *A survey of behaviour in fires*, chapter 6, pages 83–95. In Canter [3], 2nd edition, 1990.

[18] Jonathan Sime. *The Concept of Panic*, chapter 5, pages 63–82. In Canter [3], 2nd edition, 1990.

[19] Erwin Kreyszig. *Advanced Engineering Mathematics.* Wiley, New York, 7 edition, 1999.