Empirical data on an evacuation exercise in a movie theater

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Abstract

Evacuation simulation receives growing interest over the last decades. It is intimately connected to two other areas of research that continuously stimulate the research in the field: pedestrian dynamics and fire safety engineering. Empirical data play a particular role in both aspects of evacuation: the movement of persons and the influence of hazards. However, in an evacuation exercise only information about the first can be retrieved, since there are no hazards present. In this paper we will – after some general remarks – present results gained from an evacuation exercise in a movie theater. 100 students took part in this exercise. They were informed about the nature of their involvement. Information about the movement of every individual was recorded using video cameras.

Key words: Evacuation, Simulation, Exercise
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1 Introduction

The focus of the paper is clearly on empirical data about pedestrian movement in a mimicked evacuation process. Since the execution of an experiment – especially where human beings are involved – needs certain considerations regarding the variables to be observed and the practical, ethical, and financial constraints. Therefore, some remarks highlighting these aspects are contained

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in this section.
The outline of the remaining sections is as follows.

1.1 General remarks

Pedestrian dynamics is a field that receives growing attention. This is due to different factors: Advances in the theory of modeling complex phenomena, the availability of powerful computer hardware enabling large scale simulations, and the increasing interest in the various fields of application.

One of those applications that has a long tradition is the analysis of evacuation processes. The intention of this paper is not to treat this topic in depth, but to focus on the possibilities to validate model assumptions and verify results of a simulation by comparison with empirical data.

In the following sections some remarks are made concerning the different aspects that have to be taken into account, the general strategy for the task of evacuation analysis, and the limits of the simulation of evacuation processes. These will be kept brief, since the focus is clearly on the data recording and evaluation which will be treated in the remaining sections.

We carried out a similar exercise in cooperation with a German high-school. The evacuation exercise was recorded on video-tapes, too. The participants were not individually marked in this case. The results will be reported elsewhere [2].

1.2 Aspects influencing an evacuation or evacuation exercise

A schematic view of the influences on an evacuation analysis can be seen in figure 1. This is only a rough classification along the lines pointed out in [3]. Other authors use the following terms: layout/geographic, behavior/occupants, demographic/distribution, hazard/propagation, availability of facilities and personnel [4].
With respect to the pursuit of this paper the rough scheme is sufficient. The concrete influences in the case studied here are the following:

(1) Environment: no hazards, no aggravating circumstances
(2) Configuration: Escape route signs
(3) Procedure: Alarm signal, staff
(4) Behavior: Route choice, walking speed, pausing for orientation

Environment

Behavior

Configuration

Procedure

Fig. 1. Influences on an evacuation: The rectangles represent the parts covered by parameters. The behavior is determined by the variables describing the movement of the evacuees [3].

1.3 Different approaches for evacuation analysis

Overviews can be found in [3,5,4]. Regression models (hydraulic/hydrodynamic), queuing models, route-choice models (mesoscopic), macroscopic models, and gas-kinetic models (differential equations), microscopic models (social force model [6–9] and Cellular-Automaton-Models (CA-Models) [10–13])

1.4 Simulation of evacuation processes

Independent from the underlying model, every simulation requires data for validating the model assumptions and verifying the results. The exercise described here was performed to provide means for testing the model and simulation results.
Therefore a simulation that mimics the experimental situation has been carried out and the results compared. The basics of the model and the simulation will be described elsewhere [14]

1.5 Benefits of evacuation analysis by simulation

Apart from the fact that a simulation based on microscopic principles (e.g., on the level of individual persons) is assumed to be closer to reality than a more coarse grained approach, there are some more advantages of basing the analysis on a computer simulation:

- Detailed information about individual egress

- Visualization
- Inclusion of behavioral aspects
- Consideration of the influences described in 1.2

2 The need for empirical data

For the validity and acceptance of an analysis the empirical data supporting the assumptions are crucial. However, data, especially on human behavior, is scarce [3,15–23].

2.1 Validation of the Model and Verification of the Results

In the case of microscopic models, the basic assumptions can be validated by comparison with detailed (concerning individuals and their movement) data. Depending on the number and type of the variables and parameters, different types of data are required. An example is the egress of one person. Recording the initial position, the exit taken, and the egress the information is similar to that available from the simulation.

Even when single person data is not available, aggregated data (like flow-density relations) can be used for comparison with the relations put into macroscopic or flow models and queuing models. A second aspect, which is equally important, is the comparison of the predicted results of an analysis or simulation with real world data (e.g., number of persons egressed versus time). Of course, the special circumstances under which the data were gained must be taken into account.

2.2 Statistical and Individual Data

Statistical Data is available for the motion of persons [24,6,25–29]. This data can be used to verify assumptions for macroscopic models (like flow-density relations) or the output of simulations based on microscopic models. To validate the assumptions and basic properties of microscopic models, this is not enough. Data about the movement and behavior (e.g., orientation frequency, reaction time) of individuals is necessary.

With respect to individual data, a basic distinction can be made: On the one hand, there are variables that are usually measured for the whole group. These data can only be measured for individuals, if they can be identified. On the other hand, there are data that do not require the identification of persons.

Fig. 2. Layout of the movie theater. The points where the persons were counted are marked by hexagons. The dashed line represents two additional stairs separated by a terrace (cf. figure 5).

Fig. 3. Positions of the cameras.

The first group comprise the following: egress time, exit chosen, and the influence of parameters on the former. The second group consists of walking speed and orientation frequency. These later will not be analyzed in this work.

The key feature of the data presented here is the recording of every individual person and his or her way out. This allows to determine individual egress times and the dependence on the initial position and the exit chosen.

3 The evacuation exercise

3.1 The layout of the building

The building was a so-called Multiplex movie theater. The details of the layout are shown in figure 2.

There are three escape routes available. In the figure there are two marked (route 1 and route 2). The third route is the one leading through the fire door. It was available but not used during the exercise. This might be due to the fact that the other two were explicitly marked as escape routes by the respective signs.

3.2 Procedure

(1) All participants wore a hat. The hats were sequentially numbered (cf. fig. 4).
(2) The number of the person for each seat was recorded.
(3) While the leader was running the alarm was triggered.
(4) The leader was stopped, full lighting turned on, and a message announced via the public address system: "There is a technical problem. Please leave the building via the marked exits."
(5) The persons started evacuating.
(6) A person was considered evacuated when she reached the street resp. parking garage.

3.3 Population

The participants were all students. Of course, this is a restriction. However, in order to keep the costs low and to overcome some practical hindrances (like encouraging enough participants, organizing the exercise, etc.), the approach has an acceptable cost-benefit-ratio.

3.4 Restrictions and Limitations

In addition to the restrictions mentioned, we would like to point out some further limitations in order to avoid any misunderstanding. Of course it is easy to discrete the procedure chosen by arguing that it is unrealistic.

- The people were informed in advance. When marking every person unambiguously, this seems to be an unavoidable restriction, at least at the moment and with the equipment available.
- The population was homogeneous.
- There were no hazards present.
- Everyone was urged to act carefully and avoid injuries.

Therefore the results should be seen as representing an optimal case. Any deviation from those optimal conditions might change the outcome dramatically. We do not claim that this exercise is realistic in the sense that it is close to what will happen in a real emergency. It is rather intended as a starting point for investigating the crowd dynamics under certain circumstances.

4 Results

The results are twofold: on the one hand the data about the motion and egress times of the single persons; on the other hand the comparison with the simulation. In figure 4 snapshots of the video camera that was placed in the theater (see figure 2) at different times are shown. This gives an impression of the sequence of the exercise. In figure 5 one can see the simulation snapshots. Only part of the egress ways is covered by the camera picture (cf. figures 2, 5). There have been further cameras recording the events at the other parts of the theater (figure 3). Altogether, five cameras were used, one in the theater and four for surveillance the exits. One exit was not used (cf. figure 2), so Camera 2 (figure 3) did not record anything.

There is a difference between the exercise and the simulation (cf. figures 5, 4). The reason is mainly due to two factors: In the simulation the persons do not

Fig. 4. Snapshots showing the evacuation exercise at times $t = 0s$, $t = 10s$, $t = 25s$, and $t = 40s$. The position of the camera can be seen in figure 3 (Camera 1).

Fig. 5. Snapshots showing the simulation at times $t = 0s$, $t = 10s$, $t = 40s$, and $t = 65s$. The original output is colored. Here, the darker the shade, the lower the velocity. Walls and seats are black, stairs and doors gray (as can be seen on the bottom right picture).

Table 1
Constitutive parameters and results of the evacuation exercise. Four persons, that could not be unambiguously identified on the videotapes due to missing hats, have been included in the simulation. The routes A and B can be seen in figure 2

	Exercise	**Simulation**
Number of Persons	97	101
Number of Seats	174 174	
Level of occupancy	0.56	0,58
Overall		
Time	66 seconds	68 seconds
Mean egress time	44.0 seconds	38.4 seconds
Median	45 seconds	39 seconds
Route A		
Time	45 seconds	68 seconds
Mean egress time	31.1 seconds	35.0 seconds
Median	31 seconds	35 seconds
Route B		
Time	66 seconds	63 seconds
Mean egress time	53.1 seconds	42.0 seconds
Median	53 seconds	44 seconds

choose their route deterministic. So there is a deviation between simulation and exercise. Furthermore, the flow of persons in the simulation is a bit lower, since they keep a minimal distance from each other, depending on the walking speed.

Apart from the statistical values, the times for the single persons have been analysed with respect to the initial position. The results are shown in table 2. From the data shown in table 2 it can be hypothesized that there is a connection between the choice of the exit and the individual egress time. To quantify this connection the mean of the times for each row and each seat number was computed as well as the ratio of persons in each row or column (same seat

Table 2
Individual egress times (until the persons had left the building) for the exercise. The rows in the table correspond to the rows of seats and the the columns to the seat numbers. The gray cells show those persons that have left the building via the rear exit (see figure 2: exit B).

Seat Row	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1										14		12		
2														
3	23	20	28	30	39	30			17					
4					35	31	32	25		24				
5	35	34	37	36		$\underline{63}$	$\underline{66}$		31	20	19			
6	25	28			$\underline{60}$	$\underline{61}$	$\underline{61}$	41	38	38	28	26		
7		$\underline{56}$		$\underline{58}$	$\underline{55}$	$\underline{59}$		45	44		40	26	23	25
8		$\underline{49}$	$\underline{56}$	$\underline{55}$		$\underline{65}$	$\underline{64}$	$\underline{61}$	42	42	42		33	
9		$\underline{48}$	$\underline{48}$	$\underline{46}$		$\underline{43}$			44	$\underline{60}$	$\underline{60}$	$\underline{60}$		41
10	$\underline{47}$	$\underline{44}$	$\underline{47}$		$\underline{49}$	$\underline{57}$	$\underline{62}$	$\underline{62}$	$\underline{51}$		$\underline{53}$	$\underline{58}$	$\underline{42}$	
11	$\underline{49}$	$\underline{48}$	$\underline{47}$		$\underline{47}$		$\underline{62}$	$\underline{62}$	$\underline{61}$		$\underline{58}$	$\underline{58}$		$\underline{60}$
12					$\underline{50}$	$\underline{41}$	$\underline{51}$	$\underline{51}$		$\underline{50}$	$\underline{46}$			
13				$\underline{53}$	$\underline{52}$	$\underline{39}$	$\underline{38}$	$\underline{39}$	$\underline{45}$	$\underline{43}$		$\underline{52}$		

Table 3
Individual egress times (until the persons had left the building) for the simulation. The rows in the table correspond to the rows of seats and the the columns to the seat numbers. The underlines show those persons that have left the building via the rear exit (see figure 2: exit B).

Seat Row	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1										8	8	5		
2													12	3
3	12	23	38	42	27	9			18					
4					47	51	39	23		10				
5	15	36	$\underline{32}$	$\underline{63}$		61	53		58	40	18			
6	15	$\underline{41}$			20	$\underline{52}$	$\underline{56}$	56	34	24	25	16		
7		$\underline{25}$		$\underline{59}$	33	44		57	60		54	51	30	42
8		$\underline{18}$	$\underline{34}$	$\underline{37}$		64	59	64	48	50	30	28	45	
9		$\underline{30}$	$\underline{44}$	$\underline{35}$		$\underline{61}$			$\underline{46}$	$\underline{50}$	54	$\underline{43}$		21
10	$\underline{40}$	$\underline{32}$	$\underline{50}$		$\underline{45}$	68	$\underline{32}$	$\underline{60}$	$\underline{41}$		$\underline{60}$	$\underline{21}$	$\underline{19}$	
11	$\underline{29}$	$\underline{56}$	$\underline{60}$		$\underline{60}$		$\underline{48}$	$\underline{48}$	$\underline{55}$		$\underline{47}$	$\underline{39}$		$\underline{22}$
12					$\underline{27}$	$\underline{54}$	$\underline{44}$	$\underline{38}$		$\underline{21}$	$\underline{2}8$			
13				$\underline{25}$	$\underline{23}$	$\underline{56}$	$\underline{58}$	$\underline{62}$	$\underline{30}$	$\underline{39}$		$\underline{34}$		

number) that used the rear exit. The correlation coefficient for the egress time and the use of the route B for the rows and seat numbers is

$$c_{\text{row,time}} = 0.81 \tag{1}$$
$$c_{\text{seat,time}} = 0.92 \tag{2}$$

This connection between exit choice and egress time is different in the exercise and the simulation. This is due to the distance keeping implemented in the simulation.

Another important result is the usefulness of the method. We have shown that it is feasible to record an exercise using video cameras and evaluate data about single persons when marking them with appropriate means.

5 Summary and conclusion

We have reported results on an evacuation exercise performed in a movie theater. The focus was on the recording of individual movement, behavior, and especially egress times. A strong correlation was found between the choice of the exit and the individual egress time.
Furthermore, from a methodical point of view, simple measures have been tested and proven useful for marking individual persons and recording their movement. The technical equipment basically consisted of five video cameras. One compromise that must be made if the persons are recorded individually is that due to the need to mark them, they have to be informed in advance.
Another exercise was carried out and videotaped in a school. However, in this case, no individual marking was possible. The results will be reported elsewhere.

References

[1] M. Schreckenberg, S. D. Sharma (Eds.), Pedestrian and Evacuation Dynamics, Springer, Berlin, 2001, to be published.

[2] H. Klüpfel, T. Meyer-König, J. Wahle, M. Schreckenberg, Evacuation exercise in a school building: Comparison between real world data and simulation, in preparation (2001).

[3] S. Gwynne, E. Galea, M. Owen, P. Lawrence, L. Filippidis, A review of the methodologies used in the computer simulation of evacuation from the built environment, Building and Environment 34 (1999) 741–749.

[4] H. Hamacher, S. Tjandra, Mathematical modelling of evacuation problems – a state of the art, in: Schreckenberg and Sharma [1], to be published.

[5] S. P. Hoogendoorn, P. H. Bovy, W. Daamen, Microscopic pedestrian wayfinding and dynamics modelling, in: Schreckenberg and Sharma [1], to be published.

[6] D. Helbing, P. Molnar, Social force model for pedestrian dynamics, Phys. Rev. E 51 (1995) 4282–4286.

[7] D. Helbing, I. Farkas, T. Viscek, Simulating dynamical features of escape panic, Nature 407 (2000) 487–490.

[8] D. Helbing, I. Farkas, T. Viscek, Freezing by heating in a driven mesoscopic system, PRL 84 (2000) 1240–1243.

[9] D. Helbing, P. Molnár, I. Farkas, K. Bolay, Self-organizing pedestrian movement, Environment and Planing B In print.

[10] H. Klüpfel, T. Meyer-König, J. Wahle, M. Schreckenberg, Microscopic simulation of evacuation processes on passenger ships, in: Proceedings of the Fourth International Conference on Cellular Automata for Research and Industry, Karlsruhe, 2000, pp. 63–71.

[11] V. J. Blue, J. L. Adler, Modelling four directional pedestrian movements, in: TRB (Ed.), Transportation Research Board, 79th Annual Meeting, 2000.

[12] V. J. Blue, J. L. Adler, Cellular automata microsimulation of bi-directional pedestrian flows, Journal of the Transportation Research Board 1678 (2000) 135–141.

[13] V. Blue, J. Adler, Cellular automata microsimulation for modeling bi-directional pedestrian walkways, TRB 35 (3) (2001) 293–312.

[14] H. Klüpfel, T. Meyer-König, J. Wahle, M. Schreckenberg, A microscopic model for simulating evacuation processes, in preparation (2001).

[15] H. Weckman, S. Lehtimäki, S. Männikkö, Evacuation of a theatre: Exercise vs calculations, Fire and Materials 23 (6) (1999) 357–361.

[16] L. C. Boer, W. Bles, Evacuation from ships: Account for ship motion, in: Safety of transportation: Imbalance between growth and safety, Delft, 1998.

[17] L. C. Boer, A. Vredeveldt, Way-finding behaviour and technical guidance systems, in: 21st Century Cruise Ship, Royal Inst. of Naval Architecture, London, 1999.

[18] A. Brumley, L. Koss, The motor ability of passengers during the evacuation of ferries and cruise ships, Journal of Ship Research Society of Naval Architects and Marine Engineers.

[19] A. Brumley, L. Koss, The influence of human factors on the motor ability of passengers during the evacuation of ferries and cruise ships, in: I. of Naval Architects (Ed.), Conference on human factors in ship design and operation, 2000.

[20] A. Brumley, L. Koss, The need for statistics on the behavior of passengers during the evacuation of high speed craft, in: Proceedings of FAST '97 High Speed Craft Technology Conference, 1997.

[21] A. Brumley, L. Koss, The implication of human behavior on the evacuation of ferries and cruise ships, in: Proceedings of AME '98 Australian Maritime Engieneering CRC Annual Post-Graduate Conference, 1998.

[22] E. Galea, M. Owen, P. Lawrence, Computer modelling of human behaviour in aircraft fire accidents, Toxicology 115 (1996) 63–78.

[23] E. R. Galea, A general approach to validating evacuation models with an application to exodus, Journal of Fire Sciences 16 (6) (1998) 414–436.

[24] U. Weidmann, Transporttechnik der fußgänger, Schriftenreihe des IVT 90, ETH Zürich (Januar 1992).

[25] F. J.J., Pedestrian Planning and Design, Metropolitan Association of Urban Designers and Environmental Planners, New York, 1971.

[26] L. Henderson, The statistics of crowd fluids, Nature 229.

[27] L. Henderson, Sexual differences in human crowd motion, Nature 240 (1972) 353–355.

[28] Transportation Research Board, Highway Capacity Manual, 3rd Edition, chapter 13, Pedestrians (1994).

[29] A. D. Nello (Ed.), SFPE Handbook of Fire Protection Engineering, 2nd Edition, National Fire Protection Association, 1995.