Comparison of Evacuation Simulation Models

Aseri, BuildingExodus, FDS+Evac, and PedGo Applied to Auditorium

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Abstract In this paper we present simulation results for an auditorium. The results have been obtained by the programs Aseri, buildingExodus, FDS+Evac, and PedGo. Additionally they are compared to hand calculations based on Predtetschenski's and Milinski's model and a capacity analysis. Beside the calculation of RSET the focus of this paper is on the predicted locations of congestions.

Keywords Simulation • Evacuation • Aseri • BuildingExodus • FDS+Evac • PedGo • Predtetschenski & Milinski • GFPA • Auditorium

1 Safe Egress

The condition for safe egress can be formulated by the following equation:

$$\text{RSET} < \text{ASET} \tag{1}$$

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Table 1 Summary of models used

Type	Model
Capacity analysis	GFPA-Guidelines, "moderate demand"
Dynamic flow model	Predtetschenski & Milinski, ("mid-season street dress", "normal conditions")
Discrete model	buildingExodus (Ver. 4.00) (standard population)
Discrete model	PedGo (Vers. 2.5) (standard population)
Continuous model	Aseri (Vers. 4.8) ("Egress", inhomogeneous population)
Continuous model	FDS+Evac (Vers.: FDS 5.5.3, Evac 2.3.1) (standard population "adult")

The safe egress must be completed when the conditions become unsafe as given by the available safe egress time (ASET). The required safe egress time (ASET) is the sum of the intervals for detection, alarm reaction and movement time [1].

$$\text{RSET} = \text{Detection} + \text{Alarm} + \text{Reaction} + \text{Movement} \tag{2}$$

In addition to the time criterion, the formation of severe congestion must be avoided or contained temporarily and spatially to a short time span and small area. In this paper, we compare different models for the determination of RSET and additionally focus on the different predicted locations of congestions (cf. Table 1).

2 Simulation of the Required Safe Egress Time

2.1 Models Used

The models used are shown in Table 1. These are two hand calculation methods, a simpler one called "Capacity Analysis" [1] and the more complex one of Predtetschenski und Milinski (P&M) [2] taking into account the non-linear dependence of the flow on the density ("Dynamic Flow Modell"). Additionally, four computer based simulations were used. Two of them are with discrete geometry (buildingExodus and PedGo) and two with continuous geometry (Aseri and FDS+Evac). All different models have different parameters e.g. on the population or on the flow conditions to set which are for the most part not directly comparable. Therefore all models were used with their standard conditions or default settings to achieve a high level of comparability.

3 Description of the Geometry

The auditorium for which the evacuation time is determined is $34 \times 29 \times 12$ m ($L \times W \times H$) and has 20 rows with 32 seats each. Up to 640 persons seating and 360 standing might occupy the venue. There are two stairs in the middle and two

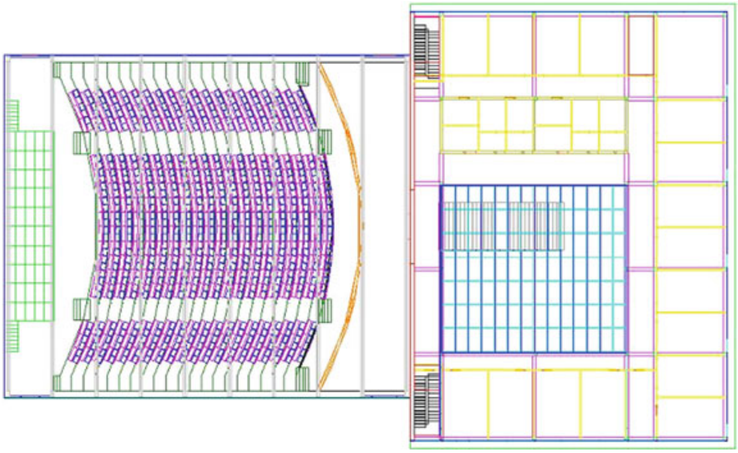

Fig. 1 Layout of the auditorium (*left*) with adjoined foyer (*right*) (Courtesy A. Weilert)

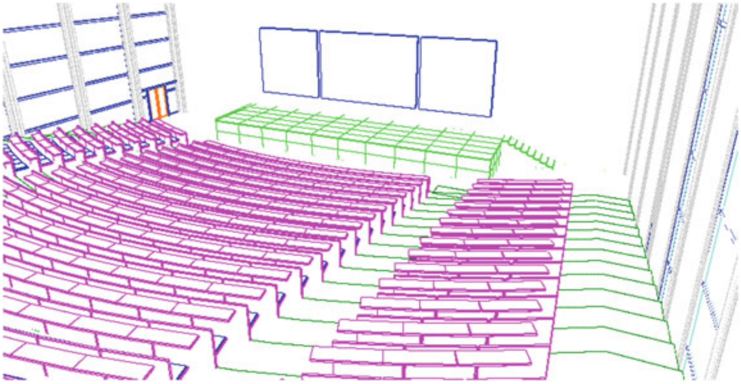

Fig. 2 Inside of the auditorium (Courtesy A. Weilert)

stairs at the side. The auditorium has two main entrance doors which lead (in case of egress) to the first floor of the adjoined foyer-building which is considered the safe area. The egress route in the foyer-building is further via one downward stair to the ground floor and outside. Additionally, two emergency exit doors are provided in the auditorium on the left and right side of the podium. The escape routes fulfill the German guidelines. The simulations with all six models were conducted for the emergency egress via escape route 1 (main entrance) and escape route 2 (emergency exits). Reaction times are not set, i.e. the evacuees are assumed to react immediately to the alarm signal. The time obtained is then the movement time.

Figure 1 shows the general layout of the building. The auditorium is shown on the left. The right part of Fig. 1 shows the main staircase in the foyer of the building in the center. The escape route is either upwards into the foyer or downwards to the emergency exits at the side (cf. Fig. 2). The everyday access to the auditorium and therefore the familiar entrance and exit to the room is route 1 (Fig. 3).

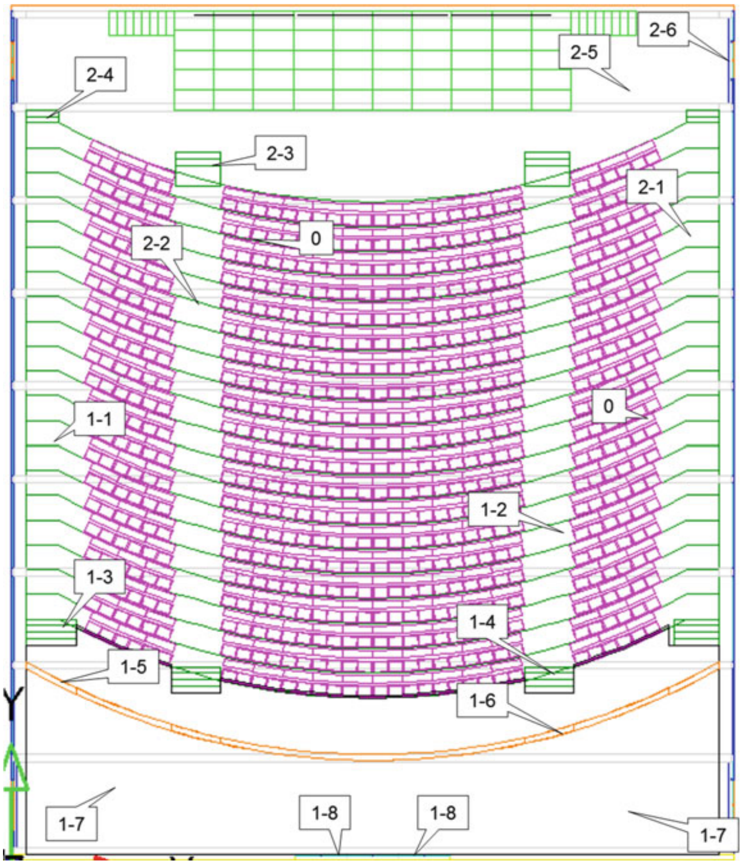

Fig. 3 Detailed view with numbering of route elements and exits

4 Flow-Based Calculations

Two different methods for flow based calculations are applied to calculate the overall movement time for the scenario described in the previous section: (1) Capacity Analysis and (2) Dynamic Flow Model. In both cases, the free widths of the escape route elements are multiplied with the specific flow to obtain the effective flow (column 6 in Table 2).

4.1 Results of the Capacity Analysis

For the Capacity Analysis the movement parameters shown in Table 2 were used which are given in the GFPA-Guidelines [1] and had been derived from [11]. For route 1, the overall evacuation time is 304 s. For route 2, the time is 298 s.

Table 2 Input parameters and results for the capacity analysis

1 No.	2 Route element	3 Number [−]	4 Effective width [m]	5 Specific flow [P/(m*s)]	6 Flow [P/s]	7 Total flow [P/s]	8 Maximum length [m]	9 Velocity [m/s]	10 Walking time [s]
0	Aisle	120	0.42	—[a]	0.63[a]	75.60	–	–	–
1-1	Outer stairwell	2	1.20	0.8[b]	0.96	1.92	10.0	0.6	16.7
1-2	Central stairwell	2	1.80	0.8	1.44	2.88	10.0	0.6	16.7
1-3	Stair	2	1.60	0.8	1.28	2.56	1.5	0.6	2.5
1-4	Stair	2	2.00	0.8	1.60	3.20	1.5	0.6	2.5
1-5	Through pass	2	1.40[c]	0.9	1.26	2.52	0.3	1.0	0.25
1-6	Door	2	2.00	0.9	1.80	3.60	0.3	1.0	0.25
1-7	Floor	4	2.50	1.1	2.75	11.00	15.0	1.0	15.0
1-8	Main exits	2	2.00	0.9	1.80	3.60	0.5	1.0	0.5
1-9	Stair in foyer	2	2.40	0.8	1.92	3.84	15.0	0.6	25.0
2-1	Stair down	2	1.20	0.8	0.96	1.92	10.0	0.6	16.7
2-2	Central stair down	2	1.80	0.8	1.44	2.88	10.0	0.6	16.7
2-3	Stair	2	2.00	0.8	1.60	3.20	0.7	0.6	1.17
2-4	Stair	2	1.20	0.8	0.96	1.92	0.7	0.6	1.17
2-5	Floor to exit	4	1.20	1.1	1.32	5.28	10.0	1.0	10.0
2-6	Exit doors front	2	2.00	0.9	1.80	3.60	0.5	1.0	0.5

[a]The capacity in the rows does not depend on the width [2]. The values are for normal movement
[b]Stairwells are modelled as stairs (error on the safe side). No distinction is made between down and up
[c]If this area is used for exhibition, the minimal width must be ensured

For the escape route 1, the walking time of the first people to escape is the sum of the values of column 10 of Table 2 for the route elements 1-i. As of the outer stairwell (element 1-1) only about 5 m are used by the head of the group, only about 8.3 s are needed for this element instead of 16.7 s. The sum of the walking times is 26.6 s.

The alternative route via 1-4 and 1-6 for the other part of the auditorium is faster. Please note that we did not take into account the outside stair in the foyer (1-9), since the foyer is already considered to be the safe area. We did not calculate the time for leaving the building but for leaving the auditorium. The elements 1-1 and 1-2, 1-3 and 1-4, and 1-5 and 1-6 are assessed “in parallel” for the calculation of the flow time. Escape route element 1-8 is used by all 1,000 persons. Therefore, this is the bottleneck; since it has the lowest ratio of N/F (N is shown in column 3 and F in column 6 in Table 1). In summary, the flow time is therefore 1,000 Persons divided by 3.6 Persons per second, which results in 278 s. The total movement time is then the sum of the walking time and the flow time, i.e. 304 s.

For the alternative escape route (2-1 to 2-6 in Table 1) a similar calculation gives 20 s for the walking time and 278 s for the flow time, i.e. 298 s for the movement time.

4.2 Predtetschenski’s and Milinski’s Flow Model

The model is based on a group specific projection area, which is in our case 0.113 m^2/person. This corresponds to person’s mid-season street dress. Due to the symmetry of the auditorium, it is sufficient to focus on the escape of 500 persons via the side stairs (200 persons) and the central stairs (300 persons).

For the stairs (route element 1-1 and 1-2) the density is 8.14 persons per square meter. This value is used to determine the flow rate from the fundamental diagram in [3]. The velocity is 0.11 m/s (upstairs) and the specific flow 0.89 P/m/s. Since the specific inflow for the stairs 1-9 is 1.12 P/m/s, congestion occurs on the stairs. The inflow is determined as

$$f_{in} = \Sigma_{in} F^{i}{}_{in} / w_{in} \tag{3}$$

and compared to the maximum specific outflow

$$f_{out} = f_{out,max} / w_{out} \tag{4}$$

where w_{out} is the clear width of the downstream escape route element and $f_{out,max}$ is the maximum specific flow of the route element type obtained from the fundamental diagram, i.e. its capacity. If

$$f_{out} > f_{in} \tag{5}$$

Table 3 Summary of the movement times

	Route 1		Route 2	
Model	Time [s]	Congestion	Time [s]	Congestion
Capacity analysis	304	Exit doors (1-8)	298	Exit doors (2-6)
P&M	295	Stairs (1-1 & 1-2), Stairs in foyer (1-9)	318	Stairs (2-1 & 2-2)
Exodus	382	Stairs (1-1 & 1-2)	266	Stairs (2-1 & 2-2)
PedGo	348	(Stairs (1-1 & 1-2)), Exit doors (1-8)	276	Stairs (2-1 & 2-2)
		(Stairs in foyer (1-9))		(Exit doors (2-6))
ASERI	324	Stair (1-1 & 1-2)	311	Stair (2-1 & 2-2)
		Exit doors (1-8)		Exit doors (2-6)
FDS+Evac	373	(Stairs (1-1 & 1-2)), Exit doors (1-8)	239	Stairs (2-1 & 2-2)
Mean	338		285	

a congestion occurs and the congested flow value $f_{out,congested}$ is used for the further calculation. Since for stair 1-9 this is the case, i.e. there is congestion, the value for $f_{out,congested}$ is 0.65 P/m/s at the maximum density is applied. The 500 persons using stair 1-8 then need $500/0.65 * 2.4$ s, i.e. 318 s to pass. Adding the walking time of 39 s, and overall movement time of 347 s is obtained.

For the alternative escape route (2-1 to 2-6), an overall time of 295 s results.

5 Simulation Models

BuildingExodus was developed by the Fire Safety Engineering Group at the University of Greenwich. Model details can be found in [3]. It is a grid based model with a cell size of 0.5 m. There are various individual parameters.

PedGo is based on a square grid. The length of the square cell is 0.4 m, which allows for a maximum density of 6.25 persons per square meter. A detailed description of the model can be found on http://www.traffgo-ht.com where the users' manual is available for download.

ASERI is based on each agent searching for the shortest path. Details can be found in [10].

FDS+Evac is an extension of the Fire Dynamics Simulator (FDS) [6]. Additional model details are described in [7, 8].

6 Summary, Conclusion, and Outlook

The results are summarized in Table 3.

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