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The effect of pedestrian placement and pre-movement times on evacuation simulation

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Abstract

During a long term research in the field of evacuation simulation, one of the two most questions, which have been asked, are “Where should I place pedestrians in my evacuation simulation?” and “Which pre-movement time should I choose?”

To answer these questions, pedestrians have been placed in different locations and to show the effect of pre-movement time, pedestrians have been placed in the building and the pre-movement time interval has been varied (we choose a uniform distribution for the time interval). What we found was a boundary value, on which the influence of the pre-movement time interval on the calculated evacuation time changed.

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1. Introduction

If evacuation simulations are used to show how long it takes to evacuate a total building, many discussions between owner, responsible authorities and the simulation engineer will be done. In this case the questions are normally not a kind of “are the results correct”, they are more like “are the chosen input parameters correct”. In different literature studies about different software tools, e.g. Rogsch et al. (2007) and Weckman et al. (1999), it can
be shown, that the software tools calculate correct results of a total building evacuation if the input parameters are correct. But these studies only compare the results of simulation and real evacuation trial and the authors can perform many simulation runs until the chosen input parameters are leading to correct results. In reality, the building will be built based on the results of the simulations and evacuation trials can be made many weeks (or years) after the building was built. If the results of the trail fit to the results of the simulation, than all is OK, but if not, many problems will appear.

Because the simulation engineer is not able (time and costs are the limiting factors) to perform thousands of simulation runs to check every different parameter sets, e. g. changing the pre-movement time, different populations and placement of people in the building and different numbers of people, it will be shown by different types of buildings, how these input parameters influences the results and which statements can be made by doing only a realistic number of simulations based upon the presented results. To have a wide range of different building types, three characteristic buildings types are investigated:

- High-rise office building (HRB),
- Hotel,
- School.

All investigations are done by using the PedGo software-tool Version 2.3.1, which has been validated in different studies like Rogsch et al. (2007) and Klüpfel (2006).

2. Short review on pre-movement times and walking velocities

The pre-movement time is one of the most discussed issues in the field of pedestrian and evacuation dynamics, because the pre-movement time is based on the individual behavior of each person, thus it cannot be described in a mathematical way such as the movement of people through a building. If we compare walking times and walking distances based on individual speed, the results simulated by software tools are acceptable and the calculated average velocity of each pedestrian matches to the free walking speed of the individuals. A good overview about walking velocities in different ages is Weidmann (1993).

In the case of pre-movement time it is very difficult to make the “right choice”, because pre-movement time is based on different factors, such as recognizing the alarm signal or actual work. Observations of money brokers have shown, that they do not leave their place of work, the computer. Normal office workers for example will finish their telephone calls in a normal way or shut down the computer. In schools personal observations have shown, that teachers and classes do not react if an alarm signal appears, because they simply think that it is a joke made by some pupils. The reality has also shown, that they start leaving the classroom as the fire brigade has arrived the school area. In shopping malls normally families are waiting for all of their members (e. g. parents are searching their children) and begin then leaving the building. As we can see, the reaction time is influenced by many parameters.

That the reaction time differs in a wide range (up to 8 minutes and more) can be seen in Proulx (2002), a German paper (VDMA (2005)) shows, that there will be a mean value of 3 minutes until people start the evacuation process. Because there are different terms like delay times, response times, recognition times and so on, in this paper the term pre-movement time is used, thus this should be a neutral term.

3. Description of investigated buildings and used parameters

3.1. High-rise office building (HRB)

The investigated office building consists of three basements, one ground floor, one mezzanine floor and 22 top floors. During the evacuation trial one staircase was closed (see Seeger et al. (1978)), thus all people had to use the same staircase. In total, 427 people stayed in the top floors and were evacuated by using the evaluated staircase. Based upon this description, different populations are used inside the building: Because of the different staff inside a high-rise office building, a maximum of 880 persons inside the building has been adopted. This number is based on BGI 650 (see Verwaltungs Berufsgenossenschaft (2007)), where information about space requirements of working
places can be found. To show how different parameters can influence the total evacuation time, different combinations between the following assumptions had been made:

- Original population distribution, see (Seeger et al. (1978))
- 20, 30, and 40 persons per floor
- fast and slow walking velocities

The dimensions of one floor are 15m x 35m. It is shown (the PedGo Model) in Fig. 1, middle.

![Image of floor plans]

**Fig. 1. Floor plans of school building (left), high rise office building (middle), and hotel (right).**

### 3.2. Hotel

The hotel building is a fictive building, which represents many hotels which can be found all over the world. It is based on a demo case of the PedGo software. The hotel has one ground floor, where reception, dining rooms and 15 rooms are placed, and three top floors with 23 rooms per floor. The maximum numbers of people are 168 if all rooms are occupied by two guest. The dimensions of one floor are 40m x 13m. It is shown (the PedGo Model) in Fig. 1, right.

### 3.3. School

The investigated school building represents the average building types of schools, which can be found in Germany. The school building consists of one ground floor and 3 top floors. In the ground floor, administrative staff and conference rooms for teachers are located, thus during “normal” lessons, this floor is occupied by a very low number of persons. These small number of occupants do not influence the evacuation process, thus they will use an exit near their offices, which is far away from the staircases, which means, that pupils will not use this exit. Normal classrooms are distributed as follows: 6 classroom in the 1st floor, 32 classrooms in the 2nd floor and 30 classrooms in the 3rd floor. Rooms for special subjects like biology, chemistry or physics are also located in the first floor. In total, 1700 pupils are inside the building, based on the assumption each class consists of 25 pupils. Because pupils are a very homogenous group of people, only one velocity distribution is used. The dimensions of one floor are 60m x 100m. It is shown (the PedGo Model) in Fig. 1, left.
3.4. Free walking velocity

The PedGo software uses to describe walking velocity the value of “cells” instead of m/s. One cell is 40x40cm, thus e.g. a walking speed of 3 cells/s means 1.2m/s. To describe the velocity in a correct way, a normal distribution is used, because the speed distribution of groups of pedestrians looks like a normal distribution (Henderson (1971) shows, that it is a Maxwell-Boltzmann distribution, which is similar to a normal distribution). Free walking velocities of people with different ages can be found in Weidmann (1993), thus the two presented groups will match to a “slow” and “fast” group of pedestrians. The two groups have the following parameter sets:

- slow: min 2 cell/s, max: 5 cells/s, mean: 3 cells/s, standard deviation: 1 cell/s
- fast: min: 3 cells/s, max: 5 cells/s, mean: 4 cells/s, standard deviation: 1 cell/s

All groups are also influenced by dawdle, thus it is possible to realize velocities which do not match to 0.4m/s. The dawdle parameters used by each group are: min: 0, max: 30%, mean: 15%, std. dev.: 5%

3.5. Pedestrian placement inside the buildings

Because the distribution of people inside buildings is an important point for legal authorities to accept results of evacuation simulations, different distributions are investigated. In one set, people are placed inside the rooms or offices of the building. Also different distributions of people in floors are made, this means the total number of people has not be changed, only the number of peoples in floors. The school building for example is simulated with a total amount of 1700 people. Simulations are made by putting 150 people in the 1st floor (6 classrooms), 800 people in the 2nd floor (32 classrooms) and 750 people in the 3rd floor (30 classrooms). In another set of simulations, only the number of people has placed in the chosen floors, but there location is chosen randomly (see Fig. 2). In the last simulation set, 1700 persons are distributed randomly inside the building, and each of the top floors consists of 566 persons (total = 1698).

Fig. 2. Different possibilities to place persons (red dots, left: only in room, right: total floor used).
3.6. Pre-movement time

As shown above, the pre-movement time differs in a very wide range, thus pre-movement times between 0 min and 13 min are chosen in some cases, the interval length is 1 min. Because only the chosen interval has influence on the results, all pre-movement times intervals are from 0 min to the chosen time. Furthermore the pre-movement time is distributed by using a normal distribution to ensure that minimum and maximum values of the pre-movement time interval are not underrepresented.

4. Results

All presented results are the 95 percentage value of all total evacuation times. Each case is simulated by a minimum of 300 simulation runs to ensure that the 95 percentage is acceptable. The results are rounded to 5 seconds, because there are so many influences in reality to building evacuation, thus a 1 second exact value is very questionably.

4.1. Influence of people placement inside the building

As written above, it is a very important question if the distribution of people has an influence of the simulation result of the total evacuation time. Table 1 and Fig. 3 shows that different location of people inside the building do not influence the total evacuation time, thus only the number of people influence the result, not their location. Table 1 shows the results of simulations with no pre-movement time (slow group), Fig. 3 shows, that pre-movement times influences the total evacuation time, but there is no influence by different placements of people.

<table>
<thead>
<tr>
<th></th>
<th>HRB (427 P)</th>
<th>Hotel (168 P)</th>
<th>School (1700 P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>People only in rooms</td>
<td>8.58 min</td>
<td>2.25 min</td>
<td>4.67 min</td>
</tr>
<tr>
<td>People in the whole floor</td>
<td>8.50 min</td>
<td>2.33 min</td>
<td>4.67 min</td>
</tr>
<tr>
<td>Equal distribution in top floors</td>
<td>8.50 min</td>
<td>Equ. distribution is standard</td>
<td>4.5 min</td>
</tr>
</tbody>
</table>

Table 1. Influence of people place on total evacuation time.

Fig. 3. Influence of people placement at high rise office building and school building.
4.2. Influence of pre-movement time

The pre-movement time is the biggest uncertainty in evacuation simulations. As shown above pre-movement time differs in a wide range. The simulation results show an unexpected result, because the pre-movement time is not only “adding the pre-movement time to the without pre-movement time simulation”, it has an important influence of the density distribution by evacuating the building. As it is shown in Fig. 4 the pre-movement time has minor influence on the total evacuation time until a limit of pre-movement time. If the pre-movement time is under this limit (at the school building: 0 – 2 min) adding 1 minute of pre-movement time adds only 20 seconds to the total evacuation time. After that limit, 1 additional minute of pre-movement time adds 1 minute to the total simulation time as expected. This strange result can be explained by taking a look to density plots of the simulation. At Tab. 2, which shows different density plots of a selected staircase in each floor of the school building by using different pre-movement times, it can be seen, that with a growing pre-movement time interval the density inside the staircase decreases until there is a density inside the staircase which has no influence of the movement of people and finally on the total evacuation time. By using a short pre-movement time interval, the density inside the staircase is high and congestions appear, thus the influence of these congestions is higher than the influence of the pre-movement time interval. So, if the pre-movement time interval is enlarged, minor congestions inside the staircase appear and people are able to walk faster through the building, in other words: minor congestions inside the staircase imply a faster evacuation of the building which is repealed by the larger pre-movement time interval. So, in the school building adding 1 minute to the pre-movement time interval reduces the density inside the staircase in that way, that an evacuation with this density would be 40 seconds faster than with the density without the 1 minute larger pre-movement time interval, thus adding 1 minute to the pre-movement time interval adds only 20 seconds to the total evacuation time. If the pre-movement time interval is large enough, no density limitation inside the staircase will appear, thus the total amount of the addition to the pre-movement time interval will be added to the total evacuation time.

![Fig. 4. Influence of pre-movement time at the school building.](image)

This phenomenon can also be seen at the high-rise office building. Fig. 5 and 6 shows, that with higher densities inside the building, the pre-movement time interval must be larger until the pre-movement time has a “full” influence on the total evacuation time. This effect is not based on the chosen walking velocity, because a comparison of Fig. 5 and Fig. 6 shows, that e.g. if 30 persons inside one floor the influence of the pre-movement time interval on total evacuation time changes from low to high at ca. 7 min, and at 40 persons per floor it changes at ca. 11 min. These values are independent from the chosen free walking velocity, as it can be seen.
It is also important to mention that the 20 seconds, which are added to the total evacuation time by adding 1 minute to the pre-movement time interval are also appearing at the high-rise office building. These 20 seconds are not influenced by the origin density inside the building or the chosen walking speed, it seems to be a fixed value.
This limit, which changes the influence of pre-movement time to the simulation results from low to high, this means the value which can be found by crossing the two fitting lines of the different “section” of pre-movement time influence (see Fig. 7, value is encircled) is the important “boundary value”.

Table 2. Density distribution of different pre-movement time intervals at school building at a selected staircase.

<table>
<thead>
<tr>
<th>Pre-movement time interval</th>
<th>Pre-movement time interval</th>
<th>Pre-movement time interval</th>
<th>Pre-movement time interval</th>
<th>Pre-movement time interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 min</td>
<td>0 – 1 min</td>
<td>0 – 2 min</td>
<td>0 – 3 min</td>
<td>0 – 4 min</td>
</tr>
<tr>
<td>3rd floor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd floor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st floor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground floor</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

5. Discussion and Summary of the Results

The influence of different parameters to evacuation simulation is shown in a wide range. The main result and very important result is, that the range of the pre-movement time interval has a major influence of the pedestrian movement inside the building. The pre-movement time interval influences the density inside the staircases thus moving through the building can be fast, because no congestions appear. Thus it is possible by choosing a very wide pre-movement time interval to underestimate points in buildings, where a congestion will appear, thus the simulation can show results, which will be not real in high density situations. To work against the possibility that a pre-movement time interval is chosen in that way, that no congestions will appear inside the building, the “boundary value” is introduced. This value shows the engineer or other people, who has to estimate the simulation, which influence the pre-movement time interval has on the investigated building and how congestions can be predicted. Thus every engineer should calculate this “boundary value” to give other persons a good basis for their discussion about choosing the pre-movement time interval.

Furthermore it is shown, that not the fastest persons of a group influence the total evacuation time, but also the slowest persons influence the total evacuation time. Based on this result future discussion should not be “who fast do people walk”, they should be in that way “how slow do parts of them walk”, thus engineers and building designers should pay attention to the slowest moving group, which will use the building, not the fastest one.

This paper also shows, that the placement of people inside a building has no influence of the total evacuation time, the engineer has only to ensure, that the same number of persons uses the same staircase or exit. If people are placed only in rooms or in the total floor, this different placement methods do not influence the result of the simulation, thus discussion about “how many people are in this room” can be cancelled if there are equal rooms, like classrooms or offices. The right question must be “how many people are in this floor?” or “how many people are in the top floors?”

If this paper is seen in a more general point of view, it should give some interesting basics for future discussions. The authors hope, that a rethinking will be started steering away from calculation total evacuation times or bargain of seconds of pre-movement time intervals leading to show how this parameters influence the evacuation and how can the building redesigned in a way, that changing the pre-movement time interval has not an effect of the movement inside the building, because if changing the pre-movement time interval or the free walking velocity is
used to become a building approved by legal authorities, thus the total evacuation time is acceptable, than we should ask, if we know, what we are doing.

Acknowledgements

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References