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Investigating the effect of different pre-evacuation behavior and exit choice strategies using agent-based modeling

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Abstract

An agent-based evacuation model was used to simulate evacuation behavior for a Chinese supermarket and an international university in the Netherlands. Data on exit choice and pre-evacuation behavior were collected via questionnaires and literature review. Sensitivity analyses were conducted to test the influence of variation in pre-evacuation time and exit choice on evacuation time. Results for the supermarket are influenced by exit choice because of the long and narrow shape of the building. Simulation results for the university were most dependent on the behavior of the evacuation officers.

Keywords: Agent-based; pre-evacuation time; exit choice

1. Introduction

Many different approaches exist to modeling crowd evacuation from buildings including lattice gas models, social force models and agent-based models [1-3]. Models can be divided into two main groups, macroscopic models, in which individuals are treated as homogeneous groups displaying common characteristics, and microscopic models that focus on individual movements and characteristics. For the microscopic models, agent-based modeling (ABM) is commonly applied for evacuation simulation [4, 5]. ABMs belong to the class of simulation models that try to link the movement of the evacuees to human behavior [5]. ABMs do not focus mainly on the carrying capacity of the structure but different groups of evacuees are modeled showing a particular behavior.

To make agent-based simulation a useful tool in emergency planning and optimization of evacuation strategies, the degree of confidence in the model is crucial [6]. To derive a minimal degree of confidence, validation should be performed on the conceptual model (to determine that the theories and assumptions underlying the conceptual model are correct), on the computerized model (to determine that the implementation accurately represents the conceptual

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description of the model) and on the model output [7, 8]. To ensure the model validity, the heterogeneity of the implemented agents should reflect the true diversity of the evacuees and their evacuation behavior.

ABM evacuation models require an estimation or empirical analysis of the behavior of the evacuees. Different methods have been applied to determine agent behavior, including role-playing games [9, 10] and deductive reasoning [11]. Understanding of the human and social behavior is crucial in determining which behavior should be assigned to the simulated agents, and how to group their behavior [12]. When applying ABM for evacuation studies one of the challenges faced is how to define the groups (heterogeneity) and which behavior these groups need to display.

Reliable data on the different groups of evacuees and their according behavior is necessary for a complete validation of the model. For evacuation modeling these include the following types of data [13, 14]:

- Delay time (pre-evacuation time)
- Walking speeds
- Occupant characteristics (reactions among different types of people)
- Actions during evacuation
- Effects of obstructions in travel paths
- Exit choice

Several methods exist for gathering these data. Direct observation under emergency conditions is often required to achieve reliable input data in different kinds of environment but because these are difficult to acquire we try alternative ways. General databases exist that list values for all kinds of parameters [13] but they are based on data collected in one, or a few case situations, and little information is available about the heterogeneity of the evacuees the data was collected for. Besides the heterogeneity of the agents the geometry of the buildings is also an important factor. Zhang [15] states that few studies analyze the impact of geometry on crowd evacuation. The size of spaces and the location of obstacles can play a significant role during egress [16].

This research investigates the applicability of data from easily available sources (databases and questionnaires) by testing them for two different situations (with different geometry). A comparison is made between these data and the effect on evacuation time is measured using a spatially explicit simulation model. This research focuses on two different aspects: pre-evacuation time and exit choice.

2. Building layouts and data collection

Two different case studies were used for this evacuation study: a Chinese supermarket and an international university in the Netherlands. The international university in the Netherlands has a high diversity of staff and students in respect to nationality and cultural background, while the Chinese supermarket is occupied by primarily Chinese staff and shoppers. In this section we describe the characteristics of the two buildings and the procedures of data collection.

2.1 Chinese supermarket

The Chinese supermarket is a large underground grocery store in the city of Xi'an. The building consists of a single floor. During normal opening hours shoppers will enter the building via escalators on the left side of the building. The shopping area is approximately 260 meters long and consists of one open space with 9 different shopping sections, and shelves that are mainly positioned perpendicular to the general walking direction (Figure 1). There are 9 emergency exits.

Behavior data for the Chinese supermarket were collected in the period January 27th – February 29th 2008. Information on evacuation behavior of shoppers was collected by means of questionnaires. A total of 500 responses were collected of which 483 responses were used for the analysis. Counts were conducted to record the total number of shoppers present. During peak hour (16.00 – 17.00 hours) a maximum number of 2580 shoppers were recorded. A constant number of 9 emergency personnel are available. Shoppers are expected to vary in their familiarity with the shopping area, some of the shoppers will know the location of emergency exits and others will not. No information was collected from staff members. Staff members other then the emergency personnel were not modelled separately for this research.

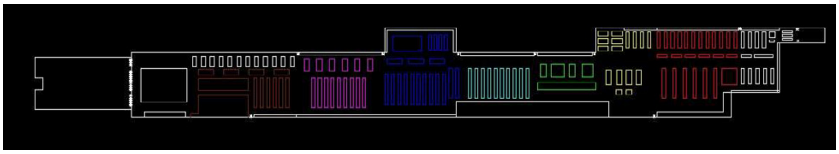

Fig. 1. Layout of the Chinese supermarket.

2.2 International university

The international university is a 6 story building. On each floor there are two emergency exits, located in the restroom areas, as well as a main staircase that will function as an additional emergency exit during evacuations. The emergency exits can also be used in normal situations as shortcuts. The structure of the building is circular with a corridor in the middle and offices and classrooms to the left and the right (Figure 2).

Occupants of this building are in general familiar with this building and are fully aware of where the exits are located. Counts were conducted to determine the number of people present at different times of day. A maximum number of 114 occupants were counted for floor 1, of which half were staff members the other half students.

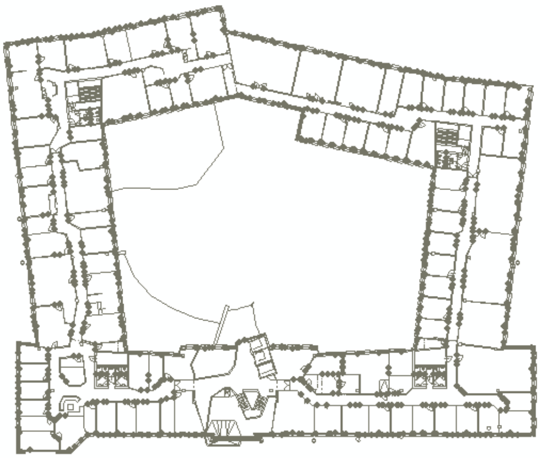

Fig. 2. Layout of the university building.

Evacuation behavior data were collected via questionnaires and evacuation trials. A total number of 63 questionnaires were handed out of which all were used for this study. Information of emergency trials was obtained from the evacuation officers. This information included a description of the behavior of evacuation officers during evacuation.

3. Analysis of behavior data

In this section we describe data found via literature review and the results of the questionnaires.

3.1 Databases

General data are collected from published databases for the two case studies for the aspects of exit choice and pre-evacuation time.

An important aspect of the total evacuation time is the amount of time that occupants delay before they begin to evacuate. Pre-evacuation time is also called “initial response time” or “pre-movement time”[14]. Gwynne et al. list that the pre-evacuation time for a school for staff is between 0-246 seconds with a mean of 70.8 seconds, and for students 8 – 200 seconds with a mean of 73.7 seconds [13, 17]. It should be noted however that this research included staff members with pre-nominated task of sweeping the rooms which in our research is identified as a specific group of staff not included in the normal analysis. Frequency distribution in the work of Gwynne et al. shows several consecutive peaks of which the first occurs around 60 seconds, the second at 150 seconds and the third at 270 seconds.

For large retail stores Shi et al. [13] list values for pre-evacuation time per shopping section and not for the total store, but the variation is not very large. Mean pre-evacuation time for stores ranges from 21.1 to 29.6 seconds with a minimum of 18 and a maximum of 45.6 seconds. For the pre-evacuation time according to influencing factors, the following data are mentioned by Shi et al [13], notify others: 10 seconds, collect belongings 30 seconds, shut down equipment 20 seconds, rescue 30 seconds, call fire brigade 30 seconds.

Data for exit choice on retail stores was also found in Shi et al [13]. The following information was listed: Familiar exit 19.5 %, Nearest Exit 50.1%, Directed by staff 25.2%, followed others 5.2%. Ko et al. [18] list information on exit choice from trial evacuation results for industrial premises. Assumption is that occupants are familiar with the building which in line with expectations for the university building. From their results it was derived that 13% walked back to the (familiar) entrance. Other occupants of the building used the nearest (emergency) exit. For this research we assume that pre-evacuation time will be longer for the university as staff and students may want to return to their office to collect belongings. In the supermarket this is not the case.

3.2 Questionnaires - Supermarket

Results from the questionnaires collected in the Chinese Supermarket related to pre-evacuation behavior are summarized in Table 1. Only 29% of the people indicate that they will leave immediately, the other 71% will either perform some pre-evacuation actions (61.4 %) or will not leave on their own account (9.7%).

Table 1. Results questionnaire Chinese supermarket on pre-evacuation behavior.

Pre-evacuation behavior	Frequency	Percentage
Press alarm	124	25.7
Leave the scene immediately	140	29
Collect personal belongings	53	11
Help others	54	11.2
Try to save life and property	65	13.5
Stand in the same place	47	9.7

Results of the questionnaires for the supermarket related to exit choice are shown in Table 2.

Table 2. Results questionnaire for the Chinese supermarket on exit choice.

Exit Choice	Frequency	Percentage
Follow others	101	20.9
Return to main entrance	101	20.9
Use emergency exit	235	48.6
Other	46	9.5
Total	584	100

A majority of people indicate that they will use the nearest emergency exit (48.6%), but a considerable number of people will also return to the main entrance (20.9%) or follow others (20.9%). These findings are in line with the results found in literature[13].

3.3 Questionnaires - University

Data were collected by dividing the occupants of the building in two groups, students and staff. Questionnaires were handed out to a random selection of both staff and students. Compared to the supermarket the number of people per square meters is not very high. People are not spread randomly over the area but both staff and students have pre-designated areas.

Table 3. Results questionnaires for the international university on initial evacuation behavior.

	Frequency student	Percentage student	Frequency staff	Percentage Staff
evacuate immediately	11	28.2	8	33
collect belongings	14	35.9	13	54
wait for teacher / students	7	17.9	0	0
help others	7	17.9	3	13
Total	39	100.0	24	100

The largest group of people, both staff and students (Table 3), indicate in the questionnaire that they will collect their personal belongings before evacuating. Only 28.2 % for students and 33% for staff members indicate that they will evacuate immediately.

Table 4. Results Questionnaire University exit choice.

	Frequency student	Percent student	Frequency staff	Percent Staff
return to where entered	2	5.1	0	0
follow emergency exit signs	27	69.2	13	54
follow other people	2	5.1	0	0
use main staircase	2	5.1	1	4
use closest stairs	5	12.8	9	38
other	1	2.6	1	4
Total	39	100.0	24	100

Results of exit choice are presented in Table 4. Some differences exist between staff and students in relation to exit choice. Both groups have a high percentage of people following the exit signs (70% for students and 54% for staff). This is remarkable as all people are familiar with this building and should not need to use the exit signs to find the nearest exit. According to the results of the questionnaire the number of people following others is very small, also in comparison to the results of the Chinese supermarket.

For this research the responses to the questionnaires were grouped (table 5) to create two types of agents: followers (follow others) and leavers (leave individually). The group identified in the questionnaire as “Wait for teacher” were taken as student followers. The combination of the three other groups (evacuate immediately, collect belongings and evacuate, help others) were identified as leavers. No followers were identified for the staff.

Table 5. Groups

groups	Questionnaire Percent
Leavers staff	100
Leavers students	72
Followers staff	0
Followers students	18

4. Prototype of the agent-based simulation model

A Prototype of an agent-based evacuation simulation model has been developed in Netlogo. This section describes the implementation of human and social behavior and the walking model of the prototype model.

For both case studies the geometry of the building was prepared consisting of obstacles (walls, void spaces), walking space and exits. Functional surfaces were generated including a network model of centerlines for corridors and rooms, distance raster layers representing the distances to different exits, and a visible exit layer.

In the model three different agents are implemented being the “leavers”, “followers” and the “officers”. The evacuation starts with the moment the alarm sounds. Assumption for both case studies is that agents are distributed randomly over the area. It is assumed that all agents hear the alarm and respond to it. For the simulation the cause of the alarm is not specified. The reason for the alarm, like for example a fire, is not visible to the agents.

4.1. Agent Behavior

Officers

The officers are trained emergency personnel in the case of the supermarket. For the university, the officers are staff members that had professional evacuation training and are responsible for the evacuation of the building. The main behavior of the officers consists of clearing the building. When the officer runs into a leaver or follower who has not yet started the evacuation process the officer will prompt the agent to evacuate. This is represented by an interaction time. After confirming that the floor is empty the officers will evacuate themselves to the nearest exit.

Leavers

Leavers represent shoppers / students and staff members that can evacuate on their own. Crucial to their evacuation behavior are the pre-evacuation time and the choice of exit. The number of leavers is derived from counts that took place for both the supermarket and the university building and the percentage of leavers as determined in the questionnaires. The exit choice was also derived from the results of the questionnaires. The pre-evacuation time was taken from literature and implemented for staff and students separately.

Followers

Followers represent people that for different reasons do not evacuate independently but will evacuation together with either a "leaver" or an "Officer". This is a complex agent-group as it is unknown why these people do not evacuate. Behavior is implemented in such a way that followers will follow either a leaver or an officer when they happen to be in the direct vicinity. If there is no other type of agent nearby the follower will not evacuate unless this follower is very close to an exit. As the follower has no individual evacuation behavior, there is no preferred exit or pre-evacuation time.

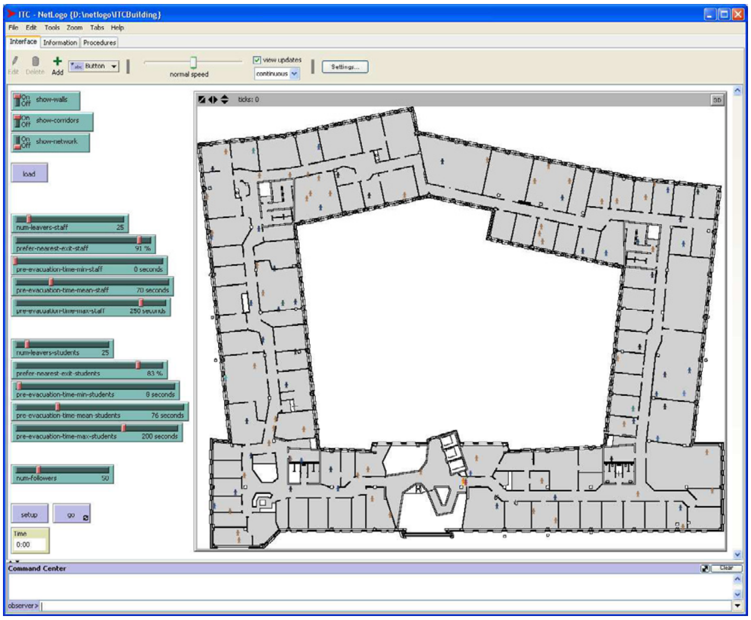

Fig. 3. Simulation interface

4.2. Walking model

The movement model is specific to the type of agent and the type of environment. For all agents walking speed is between 1.2 m/s and 1.8 m/s. Agents occupy a space of 0.3 by 0.3 meters and multiple agents can not occupy the same space at the same time. For the Chinese supermarket the total area is divided into compartments that are assigned to a specific officer. These officers are bound to stay within this area unless he/she is guiding a number of evacuees to an exit, or after having confirmed that the area is clear and is evacuating himself. Within the assigned area, officers display random movement; however this will change when moving towards an exit. For the officer in the university, movement is steered by two principles, the center line network model of corridors and rooms and the location of the other officers. As the officers work in pairs, each one will only concentrate on the left or right side of the network. This behavior will again change its movement when evacuating itself. Movement of the officer is interrupted for "communication time" whenever an evacuee is found in a room the officer is responsible for, the officer will stop moving. Movement of the officer will resume when the evacuee moves out of the room towards an exit. Officers will enter every room (including restrooms) as far as needed to completely view all walls and corners.

The movement of leavers is a free-space movement. They avoid collision with obstacles and other agents and move to their destination according to the shortest path (were the destination can be the closest exit, or any other exit indicated in their preferences).

The movement of the followers depends on the distance from an exit. When a follower is within eye distance of an exit, it will behave like a leaver and will evacuate itself. When this is not the case, the follower will display random movement until it is either picked up by an officer or by a leaver. It can be the only person following, or can become one of a group of followers. The model assumes that followers will continue to follow until they have reached an exit.

5. Sensitivity analysis

A sensitivity analysis was performed to evaluate the effect the choice of values has on the outcome of the total evacuation time for different variables. Two variables were tested: pre-evacuation time and preference of exit. For both buildings, nearest exit refers to either an emergency exit or the main entrance depending on which one is closest. In both situations it is assumed that all exits are accessible.

5.1. Exit choice University

Test runs were conducted with the initial set of parameters derived from the questionnaire information. For the university 114 agents were used, 57 staff and 57 student agents, as this was the highest number of people counted on this floor. For each set of parameters 25 runs were performed. Four tests were conducted for the basic settings (Table 6) and 80%, 75% and 70% preference for nearest exit. The results are presented in Figure 4. The figure shows that the exit choice does not greatly influence the maximum evacuation time. At the higher end of the scale (longer evacuation times), the curves for the different preferences are very similar. At the lowest end (smaller total evacuation time), we see that the 70% preference for the nearest exit leads to higher time values compared to the 75% and 80% preference but the differences are small. The mean evacuation time for all runs varied from 6:44 – 6:48 minutes. The fact that no large differences in total evacuation time were found can be explained by the fact that the distance to the main exit, from any point inside the building, is not much larger than the largest distance to the nearest exit. Walking back to the main entrance results in a relatively small amount of extra evacuation time. The impact of exit choice is small compared to the pre-evacuation time and especially to the time it takes the officers to clear the floor. Variation of evacuation time between the runs with the same preferences is caused by the random elements of the model including the random distribution of the agents over the study area. Runs with longer evacuation time are usually caused by the fact that the two teams of emergency officers do not reach each other at the moment the last evacuee leaves the buildings. They have to re-group to confirm that all people have left the floor before they evacuate themselves.

Table 6. Basic settings.

	Frequency	Pre-evacuation time min.	Pre-evacuation time max.	Pre-evacuation time mean	Preference nearest exit
Leavers staff	57	0	246	70	92%
Leavers students	47	8	200	76	82%
Follower student	10				

To confirm the findings, another set of runs was conducted in which all evacuees were forced to take the nearest exit, and a set in which all leavers were forced to go back to the main exit. For the nearest exit the evacuation time ranges from 6:12 to 7:08 minute with an average of 6:39 minute. For the main exit the evacuation time ranges from 6:19 to 9:06 minute with an average of 6:40 minute.

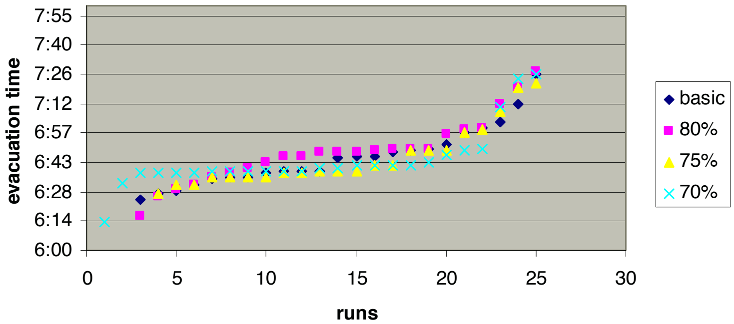

Fig. 4. Results for varying the preference for nearest exit.

5.2. Exit Choice for the supermarket

For the Chinese supermarket the exit choice runs were conducted with a total of 2000 agents. Three scenarios were evaluated: go to the nearest exit, go to a visible exit or walk back to the main entrance. Each run was repeated 50 times with all agents having the same preference. For the nearest exit total evacuation time ranges from 4:03 minutes to 11:43 minutes with an average of 7:05 minutes. For the visible exit the total evacuation time ranges from 4:24 to 15.31 minutes with an average of 8:28 minutes. For the main entrance the total evacuation time ranges from 10:51 to 11:23 minutes with an average of 11.07 minutes. Results are presented in Figure 5.

Results show that walking back to the main entrance gives a different result compared to the other two scenarios. This is caused by the long and narrow shape of this building and the relatively large distance from one end of the building back to the entrance. As the evacuees are spread randomly over the supermarket there are always some shoppers at the far end. This causes the fact that there is little variation in the total evacuation time. The other two scenarios show a similar trend with the visible exit scenario requiring a slightly longer evacuation time compared to the nearest exit scenario.

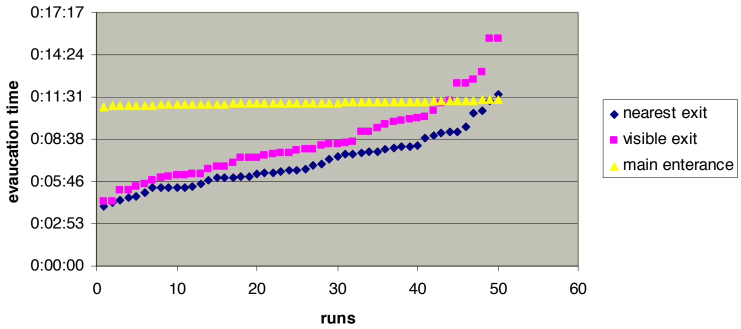

Fig. 5. Comparison of exit choice for the Chinese supermarket

5.3. Pre-evacuation time

Analysis for different pre-evacuation time was only performed for the university. Basic settings are shown in Table 6. For staff the maximum was lowered to 180 and a mean value of 65. This was done because the values listed by Gwynne et al [17] contained staff responsible for the evacuation (specific duties) which is not so in our case. They had a curve with three peaks. The last peak represented the people responsible for evacuation. The 180 value is derived from the second peak. For each pair of settings 25 runs were conducted. Results are presented in Figure 6.

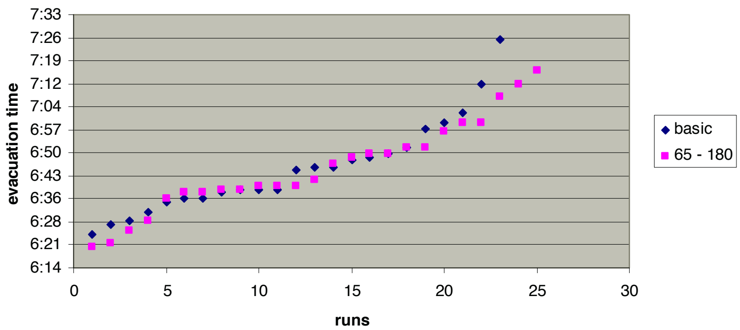

Fig. 6. Changes in pre-evacuation time for the university

Results show an evacuation time for the basic settings between 6:25 – 7:26 minutes and for the adjusted settings 6:21 – 7:16 minutes. The basic scenario does lead to a higher maximum evacuation time. However, the mean value for both series of runs remains the same (6:45 minutes).

5.4. Comparison of different scenarios

For the university building a comparison was made for the evacuation time for the individual agents. Figure 7 shows the result for the basic settings (staff pre-evacuation time 0-246, mean 70 seconds and 92% preference for nearest exit and students pre-evacuation time 8 – 200 mean 76 seconds and 82% preference for nearest exit) with the scenario where the pre-evacuation time is as specified above but the preference to the nearest exit is changed to 75% for both groups and a second scenario where the preference for the exit remains unchanged but the pre-evacuation time for both staff and students is changed to 0 – 180 (mean 65).

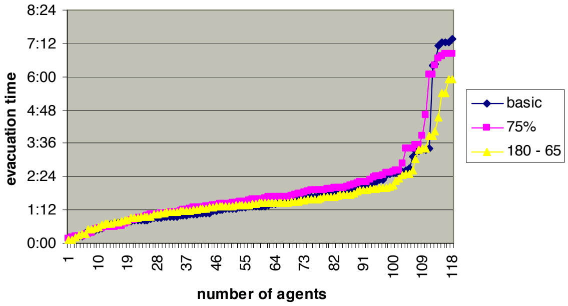

Fig. 7. Comparison of basic settings with lower preference for nearest exit (75%) and shorter pre-evacuation time (180 – 65) for the university building.

The three curves show great similarity. The curve for the lower preference for the nearest exit is slightly higher than the other two. This is because the time to walk back to the main exit is longer. Lowering the maximum and mean pre-evacuation time, does not always lead to a shorter evacuation time. Most crucial are the last agents to evacuate (including the evacuation officers).

6. Conclusions

Information was collected via questionnaires for both the supermarket and the university; however, these data did not contain all necessary information. It would have been useful to ask which pre-evacuation actions the participants expected to perform to come to a better estimate of the actual pre-evacuation time. In general, data about evacuation behavior that are collected via questionnaires are not always corresponding to behavior observed in real scenarios and can deviate per country.

Data collected via the questionnaires was compared to data found in literature. There was good agreement between data on exit choice for the Chinese supermarket and data found in general databases, but these data turned out to be less applicable for the university. Where Shi et al [13] indicated that approximately 20% will use the familiar exit, the questionnaire for the university building indicated that 10% of the students (combination of the group “where entered” and “main staircase”) and for the staff this group is only 4%.

It is sometimes difficult to make a comparison between the data obtained from databases and data required for a simulation. Part of the problem is the definition of the types of agents. For pre-evacuation time, staff members can include people responsible for the evacuation but can also refer to general staff with no particular role in the evacuation process.

The selection of the exit as indicated by the questionnaire (mainly walk to the nearest exit) is not in line with the behavior observed during evacuation drills. Video recordings of fire drills and questionnaires handed out after a evacuation exercise may give a much better inventory of the number of people that walked back to the main exit.

Only one floor of the university is included, the total building exits of 6 floors, simulating all floors together will give a much better understanding of possible problems that may develop around the staircases. The distribution of the agents over the building can also be included in the modeling process to obtain a more realistic situation.

The sensitivity analysis shows that the effect of exit choice for the university was small as the building is compact and exits are not far apart. Total walking time was affected more by the pre-evacuation time and the behavior of the officers than the exit choice. For the Chinese supermarket pre-evacuation time was much smaller and the shape of the building caused that exit choice to become important. This shows that the importance of exit choice should always be related to the geometry of the building.

Behavior of the evacuation officers for the university building is crucial in relation to the total evacuation time. Time spent looking for left behind evacuees is long in comparison to the time it takes to walk to the exit. Modeling the officer behavior in more detail will improve the model. Further improvements could include if officers enter the room, or when possible, will judge if people are inside a room standing in the doorway. Also the communication between the officers (about clearance of the floor) can be an important factor.

It turns out that the geometry of the building is very important. It influences the distance to exits and the importance of exit choice but it is also important in respect to the behavior of the officers. In the university situation, the officer behavior required the officers to enter every single room. As the supermarket is one big space the officers are responsible for a section, but this section is open and can be visually evaluated. This directly influences the walking behavior of these agents.

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