Agent Based Modeling of Citizen Evacuation Strategies

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SUSTAINABLE ENERGY TECHNOLOGY

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1 Introduction

The TU Delft Library is the largest technical-scientific library in The Netherlands. With a size of 15,000 m^2, the building hosts 450 visitors regularly. For such a huge crowded building, the evacuation procedure becomes important in case of an emergency situation. For such a concern, this report is created.

The goal of this report is twofold:

- To model the behaviour of building users during an emergency using agent-based modeling.
- To analyze the effect of users' behavior, different evacuation strategies and populations' parameters on total evacuation time.

Consequently, the following research questions are addressed in this report:

1. What is the difference in total evacuation time if all agents exit via the main entrance versus all agents exit via the nearest exit?
2. If the evacuation exit is to be varied, What are the differences in evacuation time?
3. How does gender or familiarity influence total evacuation time?

To answer these questions, Netlogo is used to model and simulate the different scenarios.

The rest of this report is organized as follows: Section 2 discusses the system identification and decomposition in terms of the main problem and actors involved. Section 3 describes the model composition. Section 4 shows the verification steps of the model. Section 5 presents and discusses the simulation results. Finally, conclusion is made in Section 6.

2 System Identification and Decomposition

This section outlines the central problem that the model will aim to investigate, along with the actors and setting where it develops. It is meant to be a generalized description. For a model-specific description of all components, please see section 3.

First, we contextualize the central problem in section 2.1. We then describe the behavior of actors in the model in section 2.2. Finally, the overall objective of the model is outlined in section 2.3.

2.1 The problem

The central focus of the simulation will be to emulate people's behavior when exiting a building during an emergency. For this purpose, a blueprint of the ground floor of the TU Delft library was provided (figure 1).

A fire alarm represents the emergency, which will be activated 30 seconds after the simulation begins. In the best possible scenario, all people should stop their activities and leave through the nearest exit as soon as possible.

However, in reality this seldom happens. Visitors may leave through the main entrance instead of the nearest one, they may ignore the alarm until they finish their task or an employee requests them to leave. Social and contextual reasons might prevent people to leave, like being in a meeting or using the toilet. This might be counteracted by active employee presence or visitors with fire training.

2.2 Actors

All actors, described as "turtles" in Netlogo, are people. They occupy a physical space in the building (meaning that a given cell can hold a limited amount of people at a given time). Their movement speed is also limited by how many people are in their vicinity. Individual attributes like

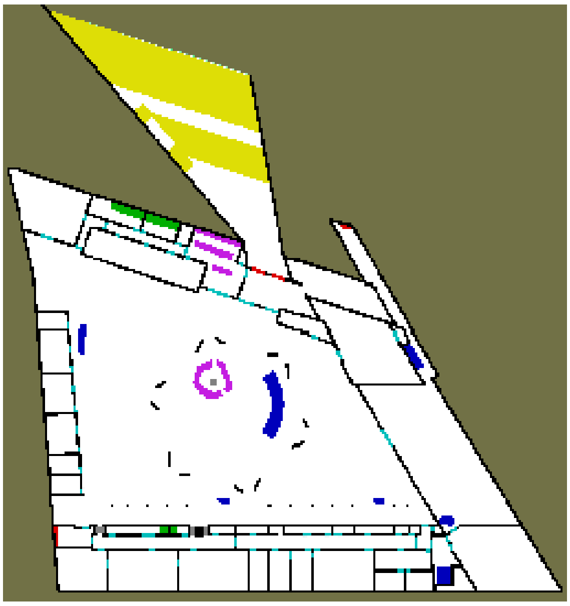


Figure 1: Ground floor of the TU Delft library, showing 3 exits (red), office spaces on the bottom, and various study spaces. The are in yellow depicts the outside of the library.

sex, age and height also influence their movement, although in our model only sex is accounted for.

The model involves two types of actors: staff (also called workers/employees) and visitors. Their individual characteristics and behavior are outlined below.

2.2.1 Staff

Staff may be clerks, cleaning personnel, office workers, etc. They may be involved in helping visitors with their tasks or carrying out their own activities. They will be present in the main area or in offices (bottom portion of figure 1).

Staff are trained, and thus always know which exit is nearest and its location. After an emergency they will aim to redirect any visitors in their vicinity to the nearest exit if they see them heading in the wrong direction, only heading to the exit once there are no more visitors near them. They always stop their activities and begin evacuation immediately.

2.2.2 Visitors

Visitors are expected to be mostly students, but they can be any other kind of person. They will have activities based on the area they are located: main area, desk, study rooms, cafeteria or bathrooms. Activity time may vary significantly among visitors, and will be primarily influenced by the section of the building they are in. Similarly, visitors may choose to ignore the alarm if people in their vicinity do not begin moving or show signs of alarm.

Some visitors might be regulars or have fire training, and will know where the nearest exit is and evacuate immediately after the alarm activates, notifying those near them of the nearest exit. All other visitors will prioritize the main exit and have a delayed response, based on their activities.

2.3 Objective

The objective of the project are twofold: first, successfully generate agents that display the behavior outlined in section 2.2 during an evacuation event as described in section 2.1. Special emphasis will be placed on the evacuation time, which is the the difference between the moment when the alarm activated (always at 30 seconds from simulation start) and the last person exited the building,

$$T_{evac} = T_{lastperson} - 30s$$

and second, to evaluate the influence of several parameters such as preferred exit, percentage of trained visitors, sex, 'alertness' threshold and distribution of employees on the total evacuation time.

3 Model

The model simulates the behavior of the agents when the emergency alarm goes off and the interaction between the workers and visitors. The model also simulates the impact on the evacuation time upon changing the different parameters described in section 2.3.

To create the model, first, some modifications are made to the skeleton of figure 3 1. Section 3.1 describe the changes as well as the model interface. Then, various assumptions are made for the simulation, described in section 3.2. Finally, the model mechanics and metrics are described in section 3.3 and 3.4, respectively.

3.1 Model Interface

The model interface includes a modified version of the map as well as the adjustable parameters. The map was colored to indicate different zones. These are:

- Main hall: white (code 9.9)
- Study area: pink (code 137.1)
- Help desk: yellowish (code 44.3)
- Food: yellow (code 44.7)
- restrooms: brown (code 35.6)
- offices: cyan (code 87.1)
- exits: red (code 14.8)
- Walls: black (code 0)

The color codes are used to distribute the agents in the setup and the number of workers in offices is, thus, controlled. Other adjustable parameters For the initial setup are:

- The number of visitors: between zero to six hundred.
- The number of workers: between zero to four hundred.
- The percentage of female agents.
- The percentage of familiar/trained visitors.
- Default preferred exit for visitors (1 = lower left, 2 = main entrance, 3 = top right).
- Time for the alarm to go off.
- The vision range: between zero to fifty patches, which is used to notify unalerted visitors by the workers and to change the alertness status of the agent depending on the number of alerted agents within the same range.
- The alert threshold: between zero and thirty, which is the required number of alerted agents in the vision of range to change the visitor status from unalerted to alerted.

Figure 2 shows the interface which includes the modified map and the parameters.

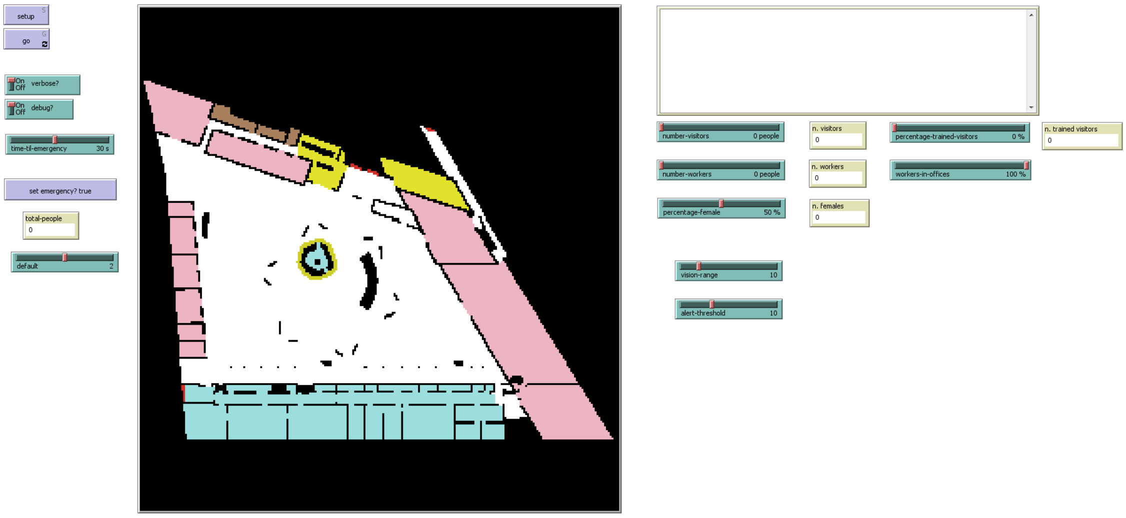


Figure 2: The Interface and the modified ground floor map, with different areas categorized with colors.

3.2 Assumptions

When building any model, assumptions must be made about the real world to make the model fit the constraints that are placed on it by the complexity of the situation. The assumptions of the model used in this project are the following:

- Since most walls in the library are made out of glass, trained visitors and workers can notify other agents in their field of vision (a perfect circle), regardless of whether this happens through a wall.
- Movement of agents happens after possible agent status updates.
- There is no time delay for trained agents informing untrained agents of the nearest exit.
- All agents know the shortest path (as defined by the algorithm) to the designated exits instantly.
- Visitors spawning in "task" locations (colored sections on the map) have no other tasks apart from ones assigned to them (eating, relieving themselves, studying/reading).
- Workers can only spawn in the main hall or office spaces. Visitors can only spawn in the public bathrooms, cafeteria, study areas or main hall.
- Untrained visitors have a set "waiting" time before heading to an exit after the alarm goes off. This delay depends on the section they spawned in (bathrooms, cafeteria or study areas like the project areas or meeting rooms). Average delay times are 3 minutes for bathroom, 45 seconds for the cafeteria and 1:30 for studying areas. These numbers were best guesses made by the team.
- When an agent's delay timer has finished, the agent do not wait for agents around them with delay timers to finish. Instead, they immediately start moving.
- Agents can have only one of two sexes (male or female).
- The speed of the agents is determined by their sex (0.9 m/s walking and 1.4 m/s running for females, 1 m/s walking and 1.5 m/s running for males). Age does not affect running speed.
- At normal state (no emergency), the maximum number of users that can stand/spawn on a patch (2.25 m^2) is four.

- If a visitor is not aware of the emergence, i.e. not alerted, he becomes alerted depending on the number of alerted people around him, this number is set by the variable threshold.

3.3 Model Mechanics

Each patch measures 1.5 by 1.5 meters and is a perfect square. The occupancy is limited to 8 people per square meter, hence there can be no more than 18 building users per patch.

The velocity of the visitors decays exponentially with the crowd density according to the observation curve of Ando et. al (Fang et al., 2003). In order to simplify the calculation and reduce the computational time, a fixed "slowness" multiplier is calculated from the curve according to the density of the crowd in the next patch (from the shortest path), as seen in table 1.

Crowd Density Person/m^2	1	2	3	4	5	6	7
Crowd Density Person/patch	2	5	7	9	11	14	16
Slowness %	100	57	43	30	30	21	0

Table 1: Crowd density effect on speed.

Visitors' age are randomized between 10 and 80. Workers are spawned during the setup either in the working area or the common area based on the workers-in-offices slider on the interface.

3.4 Model Metrics

The following KPIs are implemented as outputs from the model and used in the result section for analysis:

1. **Total evacuation time**: The total evacuation time is the time between the onset of the alarm and the last person to exit the building.
2. **Number of agents that have reached safety**: Track at each tick how many agents have reached safety. Shown in the interface under the display total-people.
3. **Average evacuation time**: This is the average evacuation time over an X amount of simulation runs for a specific setting of the parameters.

4 Verification

This section explains several different methodologies used to verify the model. Most of them are visual, since Netlogo's debugging capabilities are a bit limited.

Section 4.1 describes how pathfinding was tested. Then, section 4.2 explains how spawning locations and gender were verified. Finally 4.3 explains how the crowding effects affecting actors was tested.

4.1 Pathfinding

The pathfinding algorithm used in our model was provided by Erik Wiegel, which itself is an adapted version of the A* algorithm given by the teaching assistants for this project. Much of the underlining functionality was assumed to work by our team, since none have a background in Computer Science. However, some basic testing was conducted in order to verify that the implementation of the software worked fine.

First, the algorithm itself was tested by spawning only a small number of untrained visitors and slowing down the execution to be able to see the path taken by the turtles. This was repeated for all exits. Although some particularities were identified (see section 5.1 for more information), it was deemed effective enough for the purpose of our model.

Second, we tested if the "training" attribute of turtles worked. For this, we spawned only a few workers, distributed between offices and other areas, and saw if they headed towards the nearest exit. A small bug was fixed due to this: using 'myself' instead of 'self' in a line determining the distance between a turtle and the patches of the exits.

4.2 Actor spawning location, worker distribution and sex

Location is an important aspect of our simulation, since it determines the delay in alertness for turtles. In order to test it workers were set to only spawn in offices. Visitors should be present in all areas of the map. Figure 3 shows one of these tests, verifying that our code for location distribution works.

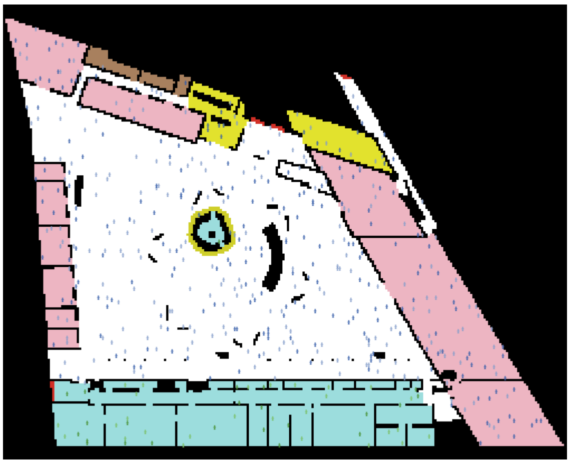


Figure 3: Test for visitor and worker spawn locations. Workers (green) only seen at offices (blue area), while visitors (blue) are present in all other sections.

A similar test was conducted for the male/female distribution slider, setting it to either 0% or 100%. A slight color variation was used to determine if turtles are male or female.

4.3 Crowding

Finally, a requirement is that the speed of agents is affected by the number of people surrounding them. Although our implementation of this is quite simple, it still needed to be tested. This was done by setting all turtles to green once the simulation begins, switching a turtle to red if it is impeded by turtles in front of it. Figure 4 shows turtles in a crowded corner.

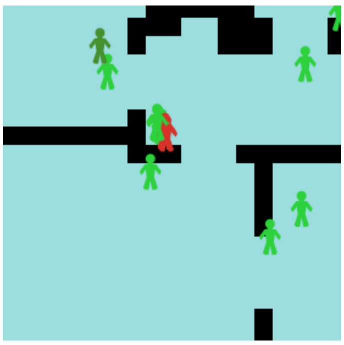


Figure 4: Visual confirmation of crowding in a corner.

5 Results

5.1 Pathing problems

While running the simulations, two major problems with the pathing algorithm were uncovered. The primary one involves the pathing itself. As shown in figure 5, instead of walking in a straight line, the algorithm tells the agents to walk at a strange angle, then curve back. This is due to how the algorithm functions: it only expands its search outwards, starting from the point closest to the exit. While the deviation in time is relatively small, this does increase computation time and could slightly increase evacuation time.

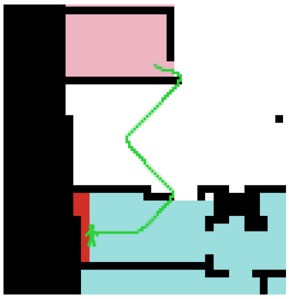


Figure 5: Sub-optimal pathing caused by the algorithm makes agents move in diagonals where straight lines might be faster.

This problem bleeds into the second problem: computation time. While running the first set of simulations (varying the preferred exit for all visitors), the simulation time was about 1 hour for both exit 1 and exit 2 (bottom left and the main entrance), or 20 simulations total. The final 10 simulations for exit 3, however, took around 30 hours to complete. This is, again, due to how the algorithm functions: because the exit is located in a weird corner of the map, most agents are first required to walk the opposite direction of the exit, which is the last direction the algorithm checks.

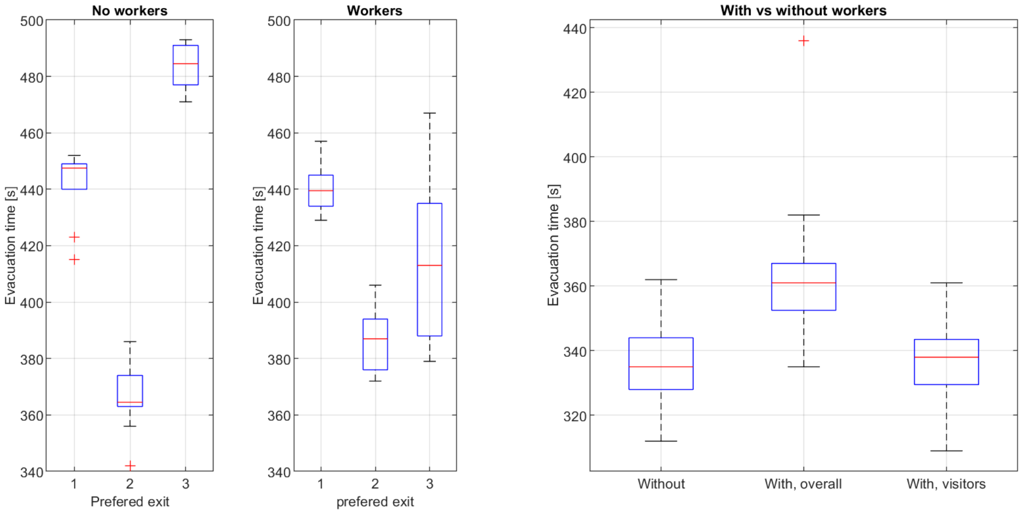
5.2 Preferred exit

For these tests, no workers were introduced in the first round, and all visitors had the same preferred exit. The second round did include workers, in accordance to the default settings, with again all visitors having the same preferred exit. To keep the number of agents consistent, the simulations without workers featured 500 visitors, while the simulations with workers featured the standard 450 visitors and 50 workers. All simulations were repeated 10 times, for a total of 60 simulations. The results are shown in figure 6a.

As becomes immediately apparent, without any workers present, exit 3 has the longest evacuation time by far, at just over 8 minutes average with a total spread of around 20 seconds. Exit 1 has an average of 7 and a half minutes, with a spread of approximately 10 seconds and two outliers of around 7 minutes total evacuation time. Exit 2 (the main exit) had the shortest evacuation time at an average of just over 6 minutes, with a spread of just over 30 seconds. One outlier had a total evacuation time of just over 5 minutes, 40 seconds.

The location of exit 3 is most likely the cause of its higher evacuation time. As it lies at the end of a long thin hallway, the number of patches that might generate visitors starting near its location are relatively small, while exit 1 is located near one of the corners of the main hall with plenty of patches available to visitors as starting locations. This coincides with the real life situations, as the hallway is closed off by an emergency exit door, so one would expect no visitors to be present in that hallway.

Some of the increased evacuation time can also be attributed to the pathing errors. In several simulations, the cornering problem as described earlier made several appearances, as the agents are required to cross several open spaces and rooms to get to the exit, with the path from one



(a) The effect of the presence of workers on the evacuation time, with varying preferred exits.

(b) From left to right: 450 unfamiliar visitors with no workers; 450 unfamiliar visitors and 50 workers; evacuation time for the last unfamiliar visitor for 450 unfamiliar visitors and 50 workers.

Figure 6: Influence of different exits and worker presence if all visitors are untrained.

door to the other not being in line with the absolute direction to the exit. This effect, however, is most likely relatively minor.

Lastly, there is a significant evacuation time increase between no workers present and having workers present when exit 2, the main exit, was preferred, at a difference of about 20 seconds. To verify this result, 100 simulations were run both with and without the 50 workers present, with 450 visitors in both cases.

Graph 6b shows some surprising results, as the evacuation time for the visitors was the same in both the cases with and without workers present. Comparing the average evacuation time without workers to the results from the first set of runs, there is a decrease of about 20 to 30 seconds in evacuation time. This could be attributed to the decreased number of agents, though this has not been verified.

What is clear however, is that the increase in evacuation time from having no workers to having workers present, is attributable to the fact that workers wait until the last visitors have left their vision range, before evacuating themselves. To its merit, all 100 runs with workers present had the last visitor leave the building between 20 and 30 seconds earlier than the last worker.

5.3 Exit Threshold

The code also includes a setting for the "exit threshold", which is the number of alerted individuals one visitor has to have near it in order to trigger its alert state and immediately start evacuating. This threshold was varied, along with the percentage of trained visitors in order to discern what was the most interesting threshold value to use for other tests.

As seen in figure 7, a low threshold (3) makes familiarity irrelevant, as it is very likely that individuals will have a least 3 other people in their vicinity, causing a cascading effect from the first agent that responds immediately to all other agents. Values of 10 or above show more deviation in evacuation times in relation to familiarity, with a threshold of 30 causing significant variability in the outliers. Thus, a value of 10 was used for most other tests, in order to make changes to other parameters more visible without producing exceeding variability.

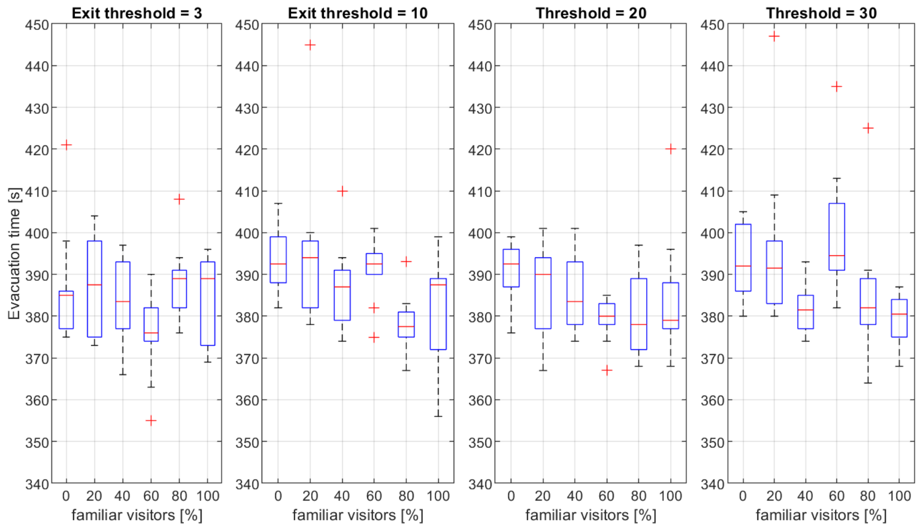


Figure 7: The effect of varying exit threshold values on the evacuation time, with varying percentages of familiar visitors.

5.4 Males versus Females

The evacuation time differences between men and women were also examined. A total of 20 simulations were done, of which 10 had an all male population, and 10 had an all female population. All other settings were set at default values.

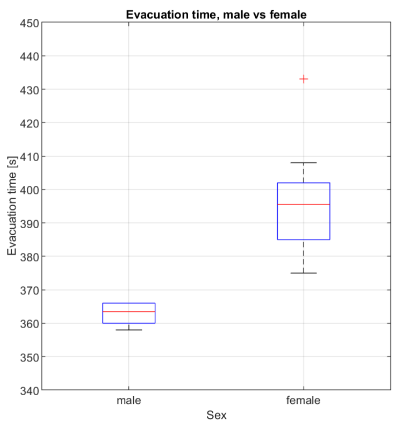


Figure 8: The evacuation time of all male versus all female workers and visitors.

The results are as to be expected. Since the sex of the agents only influences the speed of the agent, it is no surprise that an all female population will take longer to evacuate, resulting in a difference of around 40 seconds for the average evacuation time. The female population does show a larger spread in results, though this could also be attributed to the randomness in determining the agents' initial location and the relatively limited number of simulations.

5.5 Distribution of Workers

Finally, the effect of the distribution of workers between the main hall and the office spaces was also examined. To that end, the fraction of workers starting in the office spaces was varied from 0 to 100% in steps of 25%. The results are presented in figure 9.

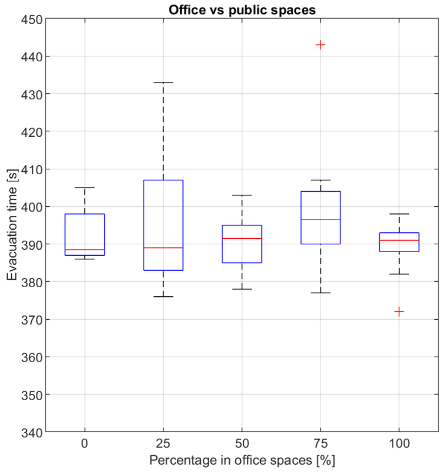


Figure 9: Evacuation time for different percentages of workers starting inside office spaces.

As shown, the average results all fall around 6 and a half minutes, with some outliers. Even at 100%, the evacuation time does not see any increase or large variation. When comparing these results to the first set of simulations (especially for preferred exit 2 in graph 6a), the average evacuation times are about equal for both, indicating that as long as there are any workers interfacing with visitors, this will significantly increase the total evacuation time.

6 Conclusion

This report describes an agent-based model for simulating an emergency situation in the TU Delft library. The model was tested with diverse simulations to answer the research questions. The following answers summarize our findings:

1. *What is the difference in total evacuation time if all agents exit via the main entrance versus all agents exit via the nearest exit (familiarity 100%)?*

   The difference was found to be slim and about only 15 seconds slower when all visitors evacuate through the main entrance.

2. *If the evacuation exit is to be varied, What are the differences in evacuation time?*

   The main entrance has the shortest evacuation time, however, the variation depends if there are workers or not, but generally, a variation of at least one minute longer was observed.

3. *How does gender or familiarity influence total evacuation time?*

   Generally, the evacuation time decreases with increasing visitor familiarity and, in contrast, increases with increasing the percentage of female visitors.