Agent Based Model of a Library Emergency at TU Delft

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Abstract. An agent based model of an emergency situation in the library of TU Delft has been created in the Netlogo environment. The model has been run with different parameters to assess the difference in average evacuation time. The ANOVA test is used to assess whether the differences in averages are significant. If all agents exit through the main exit instead of the nearest exit, the average evacuation time is significantly slower. Exit A (main exit) is the bottleneck exit; if only this exit is functional, the average time to escape is the longest compared to the other two exits. exit C is the fastest exit in this respect. In a library with only male agents, the evacuation time is an average of 12,2 seconds shorter than in a library occupied by only female agents. Form all parameters tested, a scenario where only exit A is functional increases the average evacuation time the most with 61,1 seconds. In this respect, a library filled with only 5 employees decreases the average evacuation time the most with 13,3 seconds.

Keywords: Agent Based Modelling, Netlogo, Evacuation, TU Delft, Library.

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1. Introduction and Problem Formulation

The TU delft needs to know how fast the library on the campus can be evacuated. In order to analyze this, we created an agent based model for the evacuation in Netlogo. In this report the model is analyzed in order to find answers to the following research questions:

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. Systematically vary which exits all agents will exit the building through (only A, only B, only C, A or B, B or C, A or G, etc.). What are the differences in evacuation time? How many times should you run each variation?
3. What is the difference in total evacuation time if there are signs in the building that lead the visitors to the nearest exit, compared to a building with no signs? Which assumptions do you need to make?
4. How does gender or familiarity influence total evacuation time?
5. Which parameter influence response time most

We seek to answer these questions by creating different scenarios for the model and running these multiple times. The results of these runs are then analyzed to answer the research questions. In order to make sure which of the results are significant, ANOVA tests are carried out for all of them.

One of the emergent patterns we expect to see is that people will follow others to the exits if they don't know where these are located, and that people will actively take others with them towards an exit. We expect this to happen due to the constant interaction between the different agents in regard to where they are moving.

The code is located in the following files: agents.nls, evacuation.nls, floorplan.nls, routes.nls, and utilities.nls. We decided to divide the code in files to keep it comprehensible.

2. Model Explanation

2.1 Assumptions

1. The four tasks' visitors undertake are (in order of their time to react): wander around, study together, study alone, or look for books. We made these assumptions because it is impossible to model all different activities people do in a library apart from the most obvious ones. We regard these four activities as the most logical things to do in a library and therefore we assumed that all agents are doing one of these activities.
2. Employees either stock books or wander around. Since they are employed by the library, their behavior space is more limited, and we assumed that they either wander around helping/talking to visitors or are returning the books the visitors barrowed.
3. Only employees stop their task immediately and head to the nearest exit. Visitors (including those who are frequent visitors) take a random time to react to the alarm. Some leave immediately. We assumed that if you have no sunk costs of moving to an exit (you were already wandering around), you react without hesitation. If you are concentrated at your book, you might wait a couple of seconds before you act. That is why we assume the different reaction times depending on the tasks agents have at the time the alarm goes off. Employees have a certain responsibility to guide visitors to the exit in case of emergencies and are trained/instructed to act immediately when the alarm goes off.
4. Visitors are familiar with either all three exits, only exit A, or no exits. You are totally familiar with the library and know all exits because you visit here often. If the agent just came here for the first time, we assume that the agent used the main entrance (exit A) and therefor knows this exit, and since this type of agent is here for the first time, they only know this entrance/exit. The third option is that a newcomer got disorientated once inside and forget where exit A was. So, the main assumption here is that newcomers enter via the main entrance only resulting in the knowledge of only exit A or none. Exceptions are the employees and frequent visitors, who know all exits.
5. Visitors who are only familiar with exit A, do not listen to employees who tell them to head towards the nearest exit. We made this assumption because otherwise all visitors who initially only knew exit A, would be guided by the employees to the nearest exit the instant the alarm went off. If we kept it this way, we couldn't experiment with the factor that some visitors only knew exit A and what that has for

an effect on the evacuation time, so we made them ‘deaf’ to the guidance of the employees and frequent visitors.

6. Agents can communicate through walls when telling people where the nearest exit is. Moreover, visitors escape when the majority of agents (i.e. more than half of the agents) in their vicinity leaves. They also possibly count the agents on the other side of a wall. The agents they count is based on a radius. We assume that people scream and yell when the alarm goes off in a real situation, and this is our way of reflection that in our model.
7. The employees do not wait for all visitors to have left the building before leaving themselves. They tell others in their vicinity of the nearest exit and proceed to that exit. We just simply forgot to let them stay for a while.
8. Children are not necessarily accompanied by adults. They came to the library independently. Normally a supervisor or parent would immediately look for their child when a fire alarm rings, or any random adult for that matter. In our model we assumed that everybody is egocentric and aims to bring themselves to safety, as fast as they can, so no waiting around for the independent kids.

2.2 Agents

The model contains two breeds of agents: employees and visitors. Both breeds have a male and female gender. They have the same running and walking speed: for males respectively 1 m/s and 1.5 m/s and females respectively 0.9 m/s and 1.4 m/s. Visitors who are children have a running speed of 1.05 m/s and a walking speed of 0.6 m/s. The agents are placed randomly on the map. Based on their initial location, they perform certain tasks. These will be explained hereafter.

Employees

Employees are aware of all exits.

Employees either wander around the building or stock books. They stock books when they are in the rooms on the right side of the library. Here, they move forward with a walking speed of 0.3 m/s.

Employees do wait to see what others do when the alarm goes off; they head straight towards the nearest exit. On their way, they alert others nearby of the nearest exit.

Visitors

Visitors are either aware of no exits, all exits, or only exit A.

Visitors either wander around aimlessly, or perform one of the following tasks:

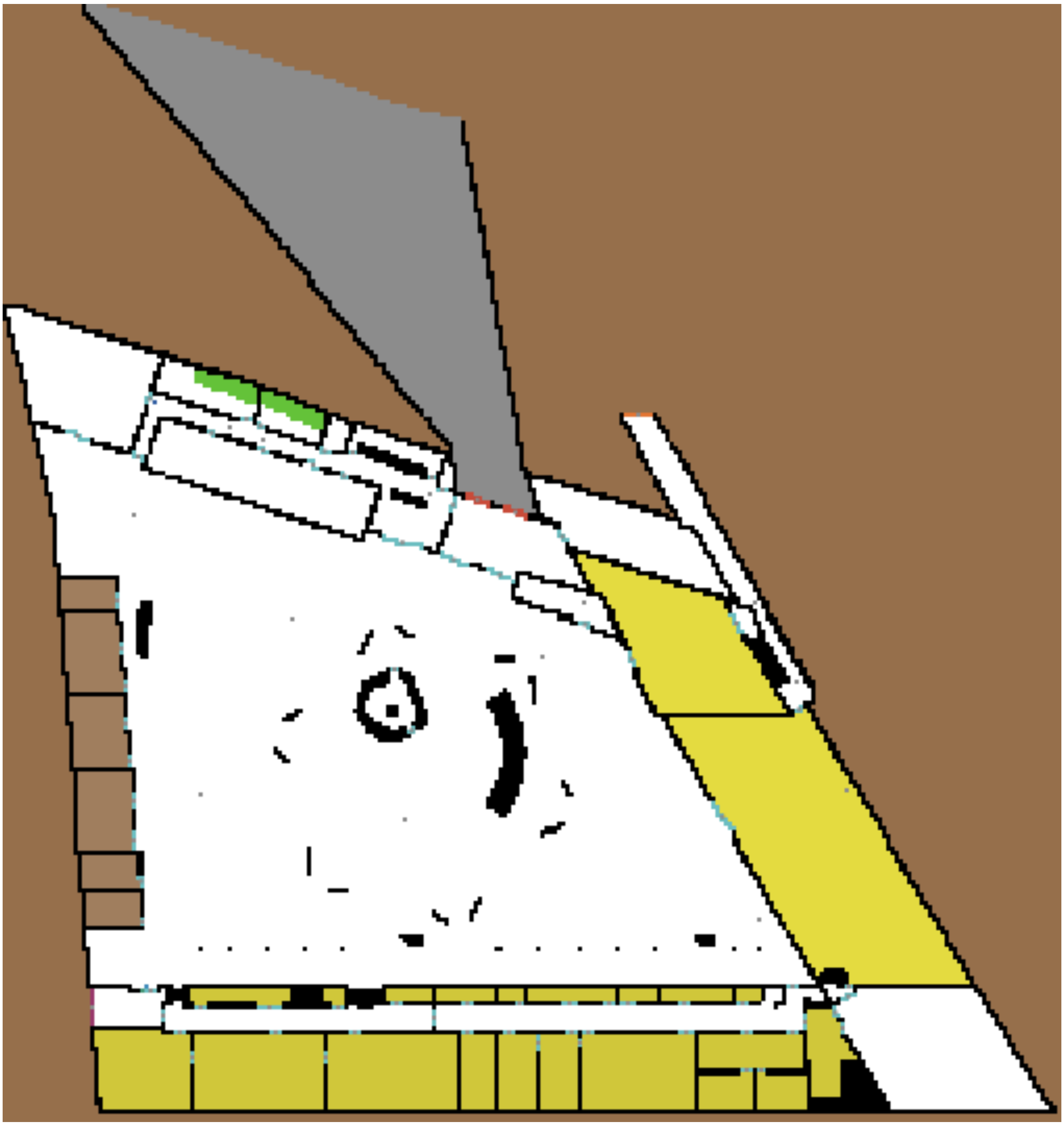
- Look for books
- Study alone
- Study together

Depending on the task they perform, their time to react to an alarm differs. When wandering around, they respond to the alarm between a randomly assigned number of 0-20 seconds. When looking for books, visitors react between 20 and 35 seconds. This choice has been made because we assumed that visitors looking for books might want to put back their books or want to continue looking for one. Visitors who are studying together take between 30 and 40 seconds to respond. Visitors who are studying together take between 20 and 25 seconds to respond to an alarm. This time is shorter than for visitors who are studying alone, because those who study together probably communicate faster amongst each other that there is a need to escape.

When the alarm goes off, visitors who do not know any exit run around aimlessly. However, when they see an employee or a visitor who knows the nearest exit, they follow them towards this exit. Visitors who only know the main exit proceed towards this exit. They do not follow others. Visitors who know all exits head towards the nearest exit.

2.3 Environment

The environment of the model is the world the agents live in. In this case it is the library of the TU Delft. In the floorplan, we gave certain areas a different color. We did this so we could assign different tasks to the visitors and the employees if they were placed there in the setup of the simulation. In these areas, which can be seen below on left, bottom and right, the visitors and the employees could perform tasks like reading books, or stocking books. Which meant that they moved slower or were not moving at all. When performing these activities their reaction time to the alarm is also different than when they were walking around the library.
Furthermore, we adjusted all the colors of the map, so that for every color there was one precise color code being used in Netlogo. So that for instance, every black patch in the floorplan was the exact same color black. This allowed us to make sure all the turtles were placed inside the building at the start of the simulation. The exits of all areas were given the color magenta, this was done as an indication for where the nodes required for the shortest path algorithm needed to be placed.



2.4 Events

When the alarm goes off (after 30 seconds), employees and visitors who know all exits head towards the nearest exit. The nearest exit is found using Dijkstra's shortest path algorithm. The algorithm follows the steps from the Wikipedia page about Dijkstra's algorithm: https://en.wikipedia.org/wiki/Dijkstra%27s_algorithm.

The shortest path is from an agent to the exit is calculated in the following way:

Step 1: all nodes are marked unvisited (Visited? false).
Step 2: the distance from all nodes is set to each exit to an infinitely high number (in our case 2^30) and the initial node is set as the current node.

Step 3: for all unvisited neighbors of the current node, the distance to them through the current node is calculated. If this calculation results in a lower number than was assigned to that node (which will always be the case with the infinite assignment at the start, and sometimes when a path between for example 3 nodes is faster than through 2 nodes) the distance to exit A, B, or C is changed to that lower number.

Step 4: if all neighbors are checked, the current node is marked as visited so it will not be checked again.

Step 5: In the end, nodes which have not been visited and have a distance to the exits set to infinity. These nodes are outside of the network and will not be considered in the shortest path.

Some employees and visitors look for a new exit every second. This is not done for every agent to prevent the simulation from running extremely slow. For these agents, each step they take, the distance between the node they are going to, and other nodes in their sight are re-evaluated. Example: a agent is moving towards node X. If there is another node in their view (node Y) with (shortest distance to exit + distance from node to agent) than node X, the agent moves towards node Y.

3. Verification

The verification process of any agent-based model, consists of 4 main parts (Nikolic et al, 2013):

1. Recording and tracking agent behavior, in which relevant metrics are identified and recorded.
2. Single-agent testing, in which the behavior of a single agent is verified.
3. Interaction testing limited to minimal model, in which the interaction between agents is tested.
4. Multi-agent testing, in which the emergent behavior of multiple agents is examined.

Some of these steps we can only partly perform, because our model has a limited number of variables and parameters we can adjust, therefore some tests are limited.

3.1 Recording and tracking agent behavior

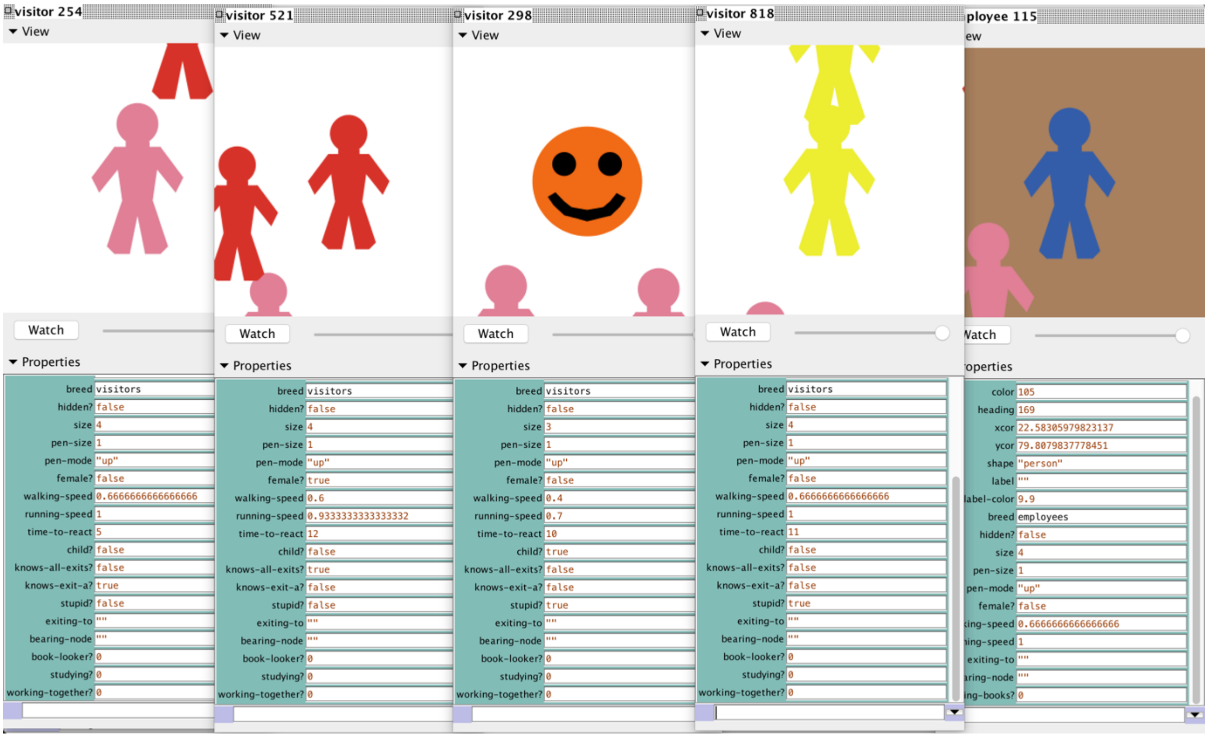
When the simulation is set up, there are multiple kind of agents in the simulation. There are the employees, visitors who know all exits, visitors who only know exit a, visitors who know no exits, and children. All of these actors where assigned a different color in the code, making them easy to distinguish.

To track their behavior and see if they were operating in a proper way, we monitored one of each of the different agents after the simulation was set up. The variables we checked were:

Breed, Female?, walking-speed, running-speed, child?, knows-all-exits, knows-exit-a, and stupid?.

In which the walking and running speed are dependent on if the agents are female, and what exit they know is assigned in code and corresponds to their color.

After the setup all of these variables were correct for all the different kinds of agents.



The only variables that should change in the simulation, are stupid?, and knows-all-exits. As the agents who knew no exits at first will find a guide who knows all exits when the alarm goes off.

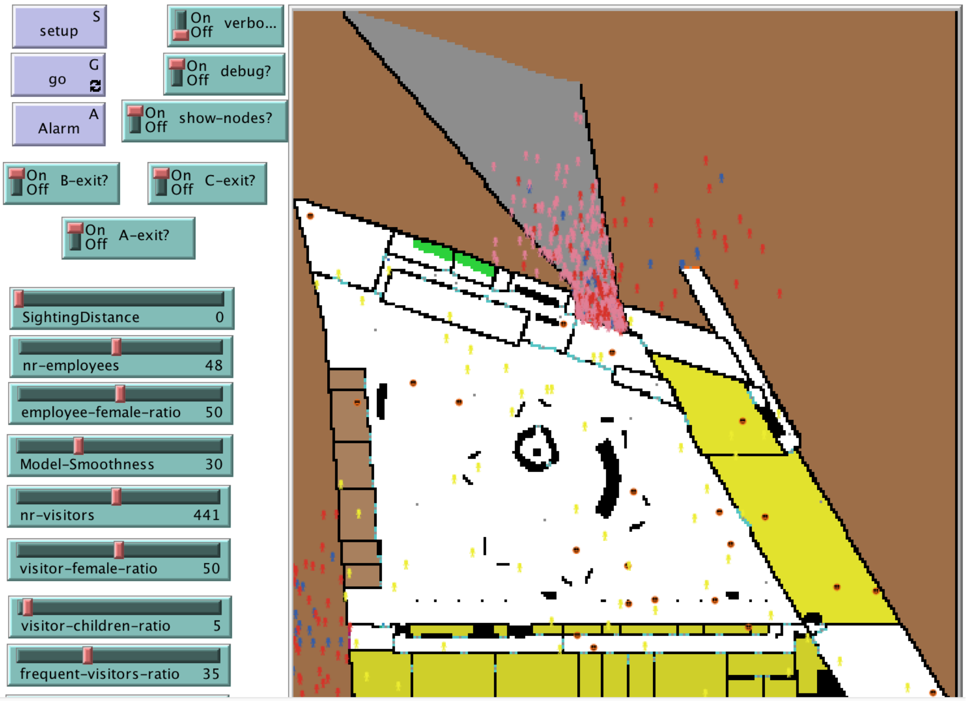
When the alarm then went off, the agents who had stupid? = true, so the agents who knew no exits and the children, turned green and had then had know-all-exits = true, indicating that the code operates intended

3.2 Single-agent testing, in which the behavior of a single agent is verified.

The single agent testing is made up of two tests, theoretical prediction and sanity check and 'breaking the agent'. In the theoretical prediction and sanity checks part, predictions are made of the behavior of an agent when given specific inputs. The breaking the agent test is about finding the limitations of the agents, by giving its parameters extreme values.

In our simulation the only input that can be varied that directly influences the behavior of the agents, is the sighting distance. Therefore, this is the only variable that we can vary to execute both these tests.

The only thing the sighting distance has direct application to is the finding of a guide for the visitors who don't know any exits. We expect that if the sighting distance is set to zero, all the visitors that don't know any exits will never find a guide and keep on wandering around meaning that they would die. If the sighting distance is at its maximum, all the visitors will almost instantly find a guide and know all exits.



As expected, when the sighting distance was set to zero, the visitors who don't know any exits, and the children remain in the library and keep wandering around. If the sighting distance was set to its maximum, they all found a guide as soon as the alarm was off and turned green.

3.3 Interaction testing

To test the interaction of the minimal model, the model is run with the least number of agents possible. In our case this means that the model is run with 1 visitor, and 1 employee.

When the model is run under these circumstances, a problem with the interaction occurs. As the different agents are often too far too see each other, it can occur that the employee leaves the building while there is still a visitor inside who doesn't know any of the exits. Therefore, this visitor keeps wandering around, and would eventually die.

3.4 Multi-agent testing

When running the model with all agents present, all of them receive the proper variables meaning that the code works properly. The effect of maximizing and minimizing the sighting distance remains the same.

4. Data analysis

4.1 How we setup the experiments

For each variable we tested, we ran a value at least 10 times. In the ‘code’ sheet, we added a counter that counts the number of ticks. Moreover, since in some runs 1 or two individuals who did not know any exits would remain lost in the building, we coded that when there are only one or two agents inside, the model stops after 20 ticks. The 30 seconds before the alarm goes off are included in the evacuation times. We sometimes had to delete the results that came out with the stop condition of 500 ticks to avoid very skewed averages.

4.2 ANOVA-test for significance

We did a single factor ANOVA test in the scenarios in order to reject the null hypotheses. The null hypotheses are in all scenarios that there is no difference with the default setting. In an ANOVA the different averages are subjected to a test and if the F value is larger the Fcritical (F>Fcrit), than the null hypotheses can be rejected. Simply meaning, there is a difference between the averages of the altered variables, it is not left to randomness or chance. All ANOVA tests are performed in the Netlogo Data Analysis file in Excel. All the full tests are in that file. For simplicity we only indicate in this report if the F is larger or smaller than the Fcrit, meaning to investigate if there is a difference. We did these tests among the variables per scenarios (i.e., males vs females) and then take the fastest or slowest (depending on the scenario) against the default. Alpha is set at 0.05.

4.3 Research questions

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. Systematically vary which exits all agents will exit the building through (only A, only B, only C, A or B, B or C, A or G, etc.).
    a. What are the differences in evacuation time?
    b. How many times should you run each variation?
3. What is the difference in total evacuation time if there are signs in the building that lead the visitors to the nearest exit, compared to a building with no signs? Which assumptions do you need to make?
4. How does gender or familiarity influence total evacuation time?
5. Which parameter influence response time most?

4.4 Hypotheses

In this section we aim to predict the outcomes of the different experiments that have been conducted with the model. We provide some thoughts in advance of the model simulation.

Scenario 1 - Only one exit accessible.

For overview purposes: Exit A is the main exit (middle-north direction in the model), B is the northern exit in the top right and exit C is the most western exit.

We expect that closing two exits due to immediate fire hazard or a collapsing etc, the evacuation time will increase. Given the fact that the library covers a large area, some agents might need to cross the entire library for the one remaining exit that is still accessible. Also, since the movement speed of the agents decreases when the path before him/her becomes more crowded, cramping all agents in one funnel at one exit would slow them more than when they are dispersed over three exits. Among the exits, we expect that exit A has the least delay because a lot of visitors only know exit A, so they would run to this exit anyway. Besides that, the area surrounding exit A is the largest and therefor has the least risk of congesting. For exit B, it is the other way around. Very narrow hallway and far less central than exit A, we think that the use of only exit B will increase the evacuation time the most. Also, visitors that only know exit A, now face the problem that exit A is closed and they depend on others to guide them to the other exits.

Scenario 2 - Only two exits accessible.

The same reasoning as in scenario 1 applies to this scenario, only in a smaller amplitude, because now two and not one exit is accessible. As was stated above, due to the larger distance some agents need to cover and the fact that the exits become more crowded when there are less options, the evacuation time will increase. Simply put, we think that closing one or two exits will result in a delay. As mentioned in scenario 1, we think that exit A is the fastest and B the slowest. Regarding this prediction, the combinations of accessible exits B+C will be the slowest, since exit A is closed. On the other hand, combinations with an open exit A (A+B, A+C) will result in less delay and between these, A+B is the slowest because exit B is slower than exit C (in our reasoning).

Scenario 3 – Vary the number of employees.

Employees know all exits, and what exit is the nearest at each position in the library. They provide guidance to visitors that don't know all exits, and in this way help them escape as fast as possible. Adding more employees than the default scenario (50 employees) will therefor result in more dispersed employees and a wider 'reach' of their guidance. Following the logic that visitors who know the nearest exit are faster in evacuating, more guidance decreases the evacuation time. Removing employees, however, has the opposite effect. A lot of visitors depend on a certain guidance ('stupid? = true' for instance) and without all-knowing employees to look for, they keep wandering the library until they come across an all-knowing visitor. So, we think that decreasing the employees will result in a larger group of wandering and stupid visitors, increasing the evacuation time. We would like to add a disclaimer; adding more employees might result in more guidance, but there is a turning point where every visitor is informed on the nearest exit and adding more employees just congests the exits more than they provide guidance. So, adding 500 employees, for example, would probably lead to an increase of the evacuation time due to congestion.

Scenario 4 - vary the sighting distance.

Imagine the library fills quickly with a thick layer of smoke from the fire, and you can't find any employee or other reference point, sounds scary right? We think so as well and suggest that decreasing the sighting distance will result in a larger group of visitors that are unguided because they can't 'see' that many patches ahead. A larger observable area of patches increases the change of spotting an employee or seeing that the majority is leaving the library, shortening the reaction time or provide a direction in which way to go. In this reasoning, increasing or decreasing the sighting distance effects the area of patches that could result in much needed help. Therefor we think that increasing the sighting distance decreases the evacuation time and vice versa.

Scenario 5 - males versus females.

Male agents have a faster running speed and thus cover distances in less time. We simply think that faster movement will result in a faster evacuation. We did take into consideration that we modelled kids, and kids know no difference in gender, and all have the same low running speed, the slowest of all agents. So, a plausible scenario would be that every run there are some kids that lag in the crowd and they eventually determine the evacuation time, regardless of the running speed of the adults. Nonetheless, we think that a male-only is still faster because kids only form a small percentage of all the agents.

Scenario 6 - frequent visitors versus only exit A

Scenario 6 compares the use of only exit A (main entrance) versus the nearest exit (100% frequent visitors) and aims to answer the first research question. We think the most difference in evacuation time will be in this scenario. The use of only exit A is probably relatively fast for a single-exit scenario (see hypotheses scenario 1), but the fact that every agent knows the nearest exit in the comparison run, and all those exits are accessible, will probably result in a very low evacuation time. So, 100% frequent will be way faster than 'only exit A', at least, that is what we think.

With the hypotheses of the six scenarios, we also indirectly provided a hypothesis for most of the research questions, except for question 3 and 5. So we'll answer them separately.

Hypothesis research question 3, signs versus no signs.

We think that adding clear signs to the ceiling, like is the case in most public buildings, results in a clear path for agents and gives them a good guidance to the nearest exit. If there are no signs, agents are more dependent on their own memory of the locations of the exits or of the memory of their neighbors. This last scenario probably results in a large group that is being guided to the nearest exit, but a group of agents will remain unknowing and keep hopelessly wandering. Whereas in the case of the added signs, each agent can individually inspect the shortest path. We think that adding signs has a significantly decreasing effect on the evacuation time.

Hypothesis research question 5, what is the most influential factor.

This is a hard one, with a lot of variables to consider. We came up with two factors that will be most influential depending on the number of agents in the library. First, let us assume that there are a lot of agents in the library (800+), then we think that crowding will become the most dominant factor. This suggests that closing certain exits will have the largest impact on the evacuation time due to congestion at the exits. If there are less agents in the building, congestion will likely be less of a problem. For that scenario we think that the sighting distance has the most impact on the evacuation time because if there are less agents, there is less chance of guidance, so the need arises to look further on the horizon in the search for a guide. If this horizon shrinks with a decrease in sighting distance, it will be harder to look for a guide and get out the library safely. That is why we think that, depending on me number of visitors, the closing of the exits and the sighting distance has the most effect.

5. Data analysis

Default setting:

1) 50 employees, 450 visitors, 5% children, 50% female (on both employees and visitors)

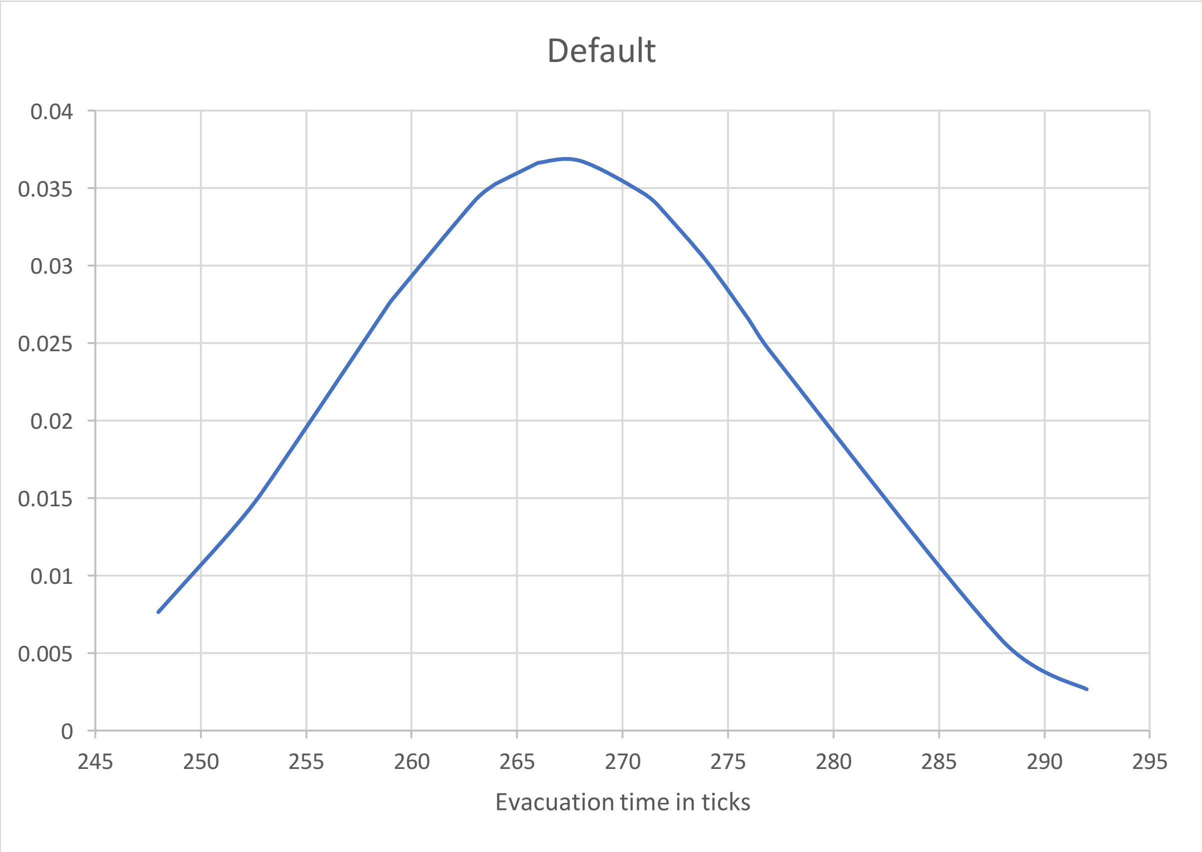
2) 35% frequent visitors -> remaining visitors: 80% only know exit A, 15% know no exit at all, children know no exits (consists of 5%).

3) Sighting distance 10

4) Model smoothness 20%

We run the default setting in order to gain insights in the normative evacuation time for the comparison of the different scenarios.

In the default situation it took on average 267,2 ticks (20 runs) for agents to evacuate the building, the standard deviation was calculated to be 10,83. This result will be used to evaluate how well the other scenarios run.



Scenario 1 - only use exit A/B/C:

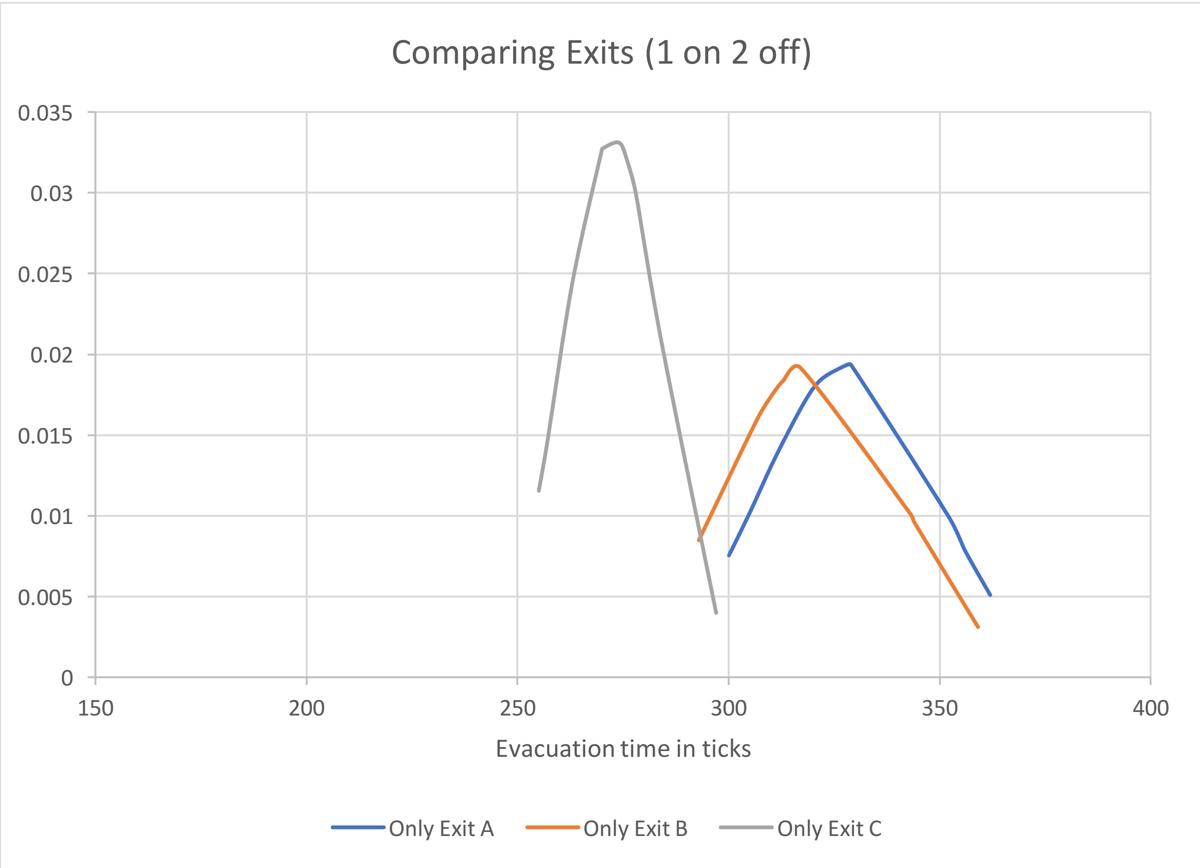
When only one of the exits was in use, the evacuation times differed. We ran the simulation 10 times for the scenario that only one of the exits was open, for all three exits. The results can be seen in the table below. Exit A is the main exit (middle-north direction in the model), B is the northern exit in the top right and exit C is the most western exit.

	Only exit A	**Only exit B**	**Only exit C**
Average	328,3	319,5	272,4
Standard Deviation	20,62	20,66	11,94
Nr of runs	10	10	10

What is interesting to see is that if only exit A was open, the average evacuation time was 328 ticks and the with that longest even though it is the most central and largest of the exits.

After exit A, exit B had the longest evacuation time taking on average 9 ticks longer for all agents to evacuate the building.

When only exit C was open, the evacuation time was significantly lower at 272 ticks. Furthermore, the standard deviation observed was almost halve that of the scenarios when only exit A or exit B where open. This evacuation time comes closest to the evacuation time in the default setting (267), yet it is still slightly slower, signaling that it is not as efficient.



Between scenarios: F = 24,51308, Fcrit = 3,354131. F > Fcrit, meaning that there is variance in evacuation time between the multiple exits. What is the impact on the default?

Only A vs default: F = 105,5969, Fcrit = 4,195972. F > Fcrit, when only exit A is open, the evacuation time is significantly slower.

Only B vs default: F = 77,17815, Fcrit = 4,195972. F > Fcrit, meaning that only exit B is significantly slower than the default.

Only C vs default: F = 1,33828, Fcrit = 4,195972. F < Fcrit, meaning that the null hypotheses (evacuation time is no different between ‘Only C’ and default) is not rejected. It can be stated that the evac time does not decrease significantly when only exit C is used.

Scenario 2 – only use 2 exits

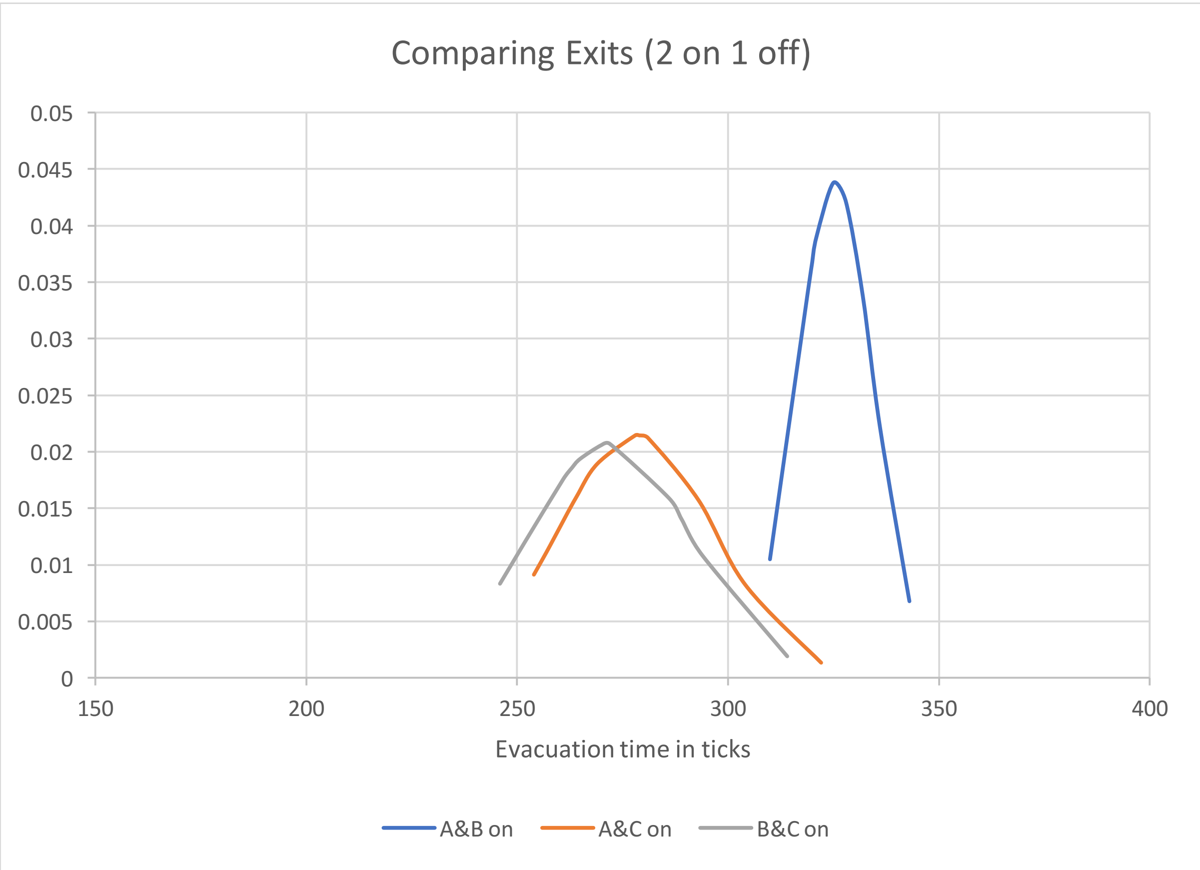
When two of the exits were in use, the evacuation time was in all cases lower than when only one of the exits was being used. This makes sense seeing as how the agents would have to on average travel less distance to an exit.

	A&B	**A&C**	**B&C**
Average	325,4	278,3	272,0
Standard Deviation	9,10	18,61	19,28
Nr of runs	10	13	12

When only exit A&B where in use the average evacuation time was the highest at 325 ticks. This is slightly lower than when only exit A was in use, yet it does seem unproportionate that an entire extra exit only leads to a 3 tick difference in evacuation time. This combination does have a significantly lower standard deviation than the A&C and B&C combination.

When exit A&C where in use the average evacuation time was 278 ticks, which is 47 tick lower than for the A&B combination. This evacuation time comes close to the default situation in which the evacuation time was 267 ticks.

The best combination of exits was B&C at 272 ticks, which is only 5 ticks slower than the default situation.



When comparing the results from the first and second scenario to the default settings, it seems that exit C somehow is instrumental for a lower evacuation time. When it is used on its own it is only 5 ticks slower than the default, and in both the combinations where C is in use the evacuation time is much lower than when it is not in use.

Among the different options: F = 94,99307, Fcrit = 3,267424. F > Fcrit, meaning a variance in the evacuation time between the different options.

A&C vs Default: F = 199,2327, Fcrit = 4,195972. F > Fcrit meaning that only exit A&C is significantly slower than default.

A&B vs Default: F = 4,40055, Fcrit = 4,159615. F > Fcrit meaning that only exit A&B is significantly slower than default.

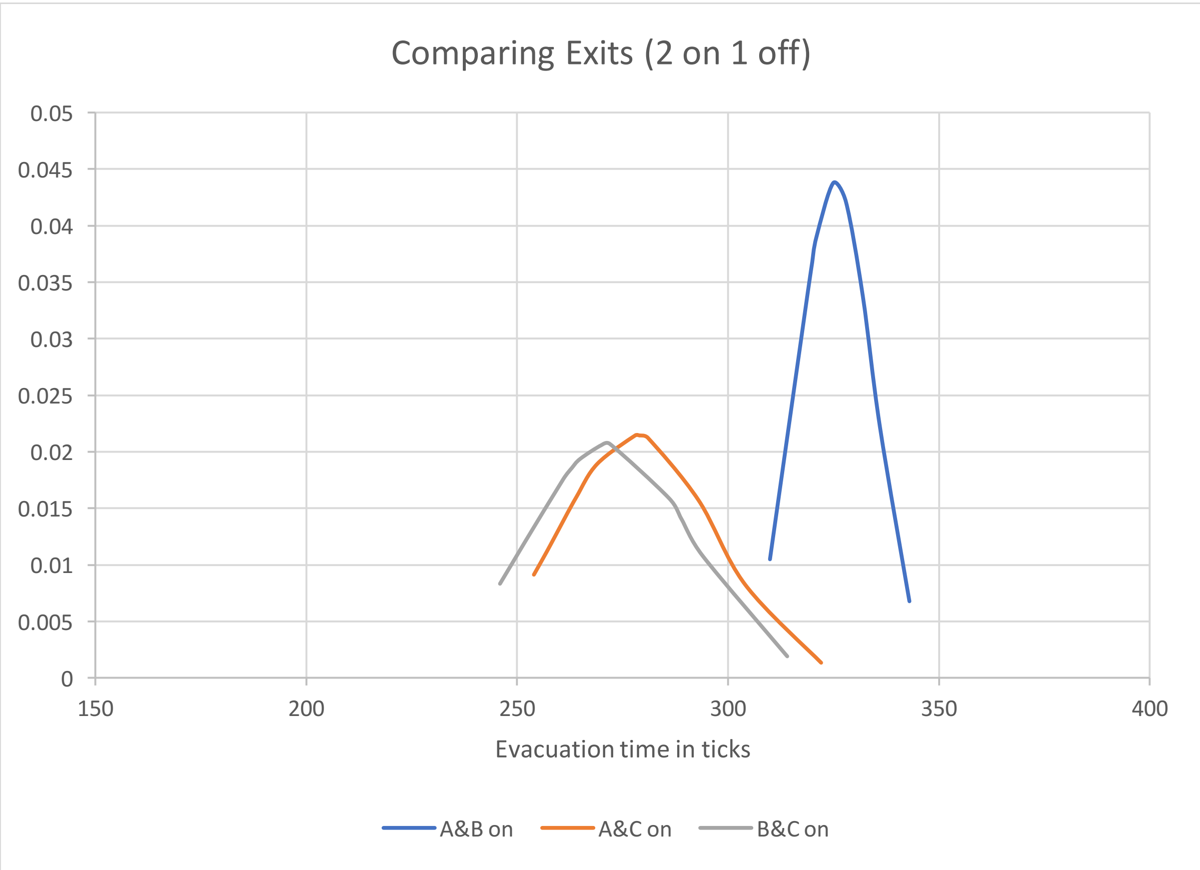
B&C vs Default: F = 0,761323, Fcrit = 4,170877. F < Fcrit meaning no variance, resulting that B&C is just as fast as the default (all three exits). Exit A, although it is the main exit, seems to have little impact on the evacuation time.

Scenario 3 - Vary the amount of employees 5 / 25 / 75 / 100

Varying the number of employees should alter the evacuation time seeing as that the visitors who don't know the nearest or any exit at all are guided to it by an employee if there is one in his sight. We thought this would mean that few employees would lead to a longer evacuation.

Number of empoyees	**5**	**25**	**75**	**100**
Average	253,9	263,63	272,83	266,63
Standard Deviation	14,72	17,32	20,40	15,95
Nr of runs	10	11	12	11

With 5 employees, the evacuation time is 267,2 – 253,9 = 13,3 seconds slower than with the default setup with 50 employees. A possible explanation for this is that the less employees there are in the building, the less crowded the exits are. When the space around the exits becomes crowded, people begin to decrease their running speed. Moreover, frequent visitors (who know all exits) also alert other visitors of the nearest exit. Since 35% of all visitors are frequent visitors, this population effectively takes over the role of employees when there are none.



What is interesting to see is that the evacuation time becomes higher going from 5 employees to 25, and again from 25 to 75. Yet when there are 100 employees the evacuation time again begins to decline. This indicates that there is a tipping point there, where it becomes more efficient for the visitors to look for an employee as a guide as they become more common than the frequent visitors who know all of the exits.

F = 2,024772, Fcrit = 2,838745. F < Fcrit, so not enough variance amongst the different numbers of employees. The extremes (5 and 100 employees) are held against the default:

5 employees vs default: F = 7,317982, Fcrit = 4,195972. F > Fcrit. Scenario with 5 employees is significantly faster than the default.

100 employees vs default: F = 0,012711, Fcrit = 4,182964. F < Fcrit. No variance among 100 employees and default.

Resulting from this, there has to be a threshold between 5 and default, where adding an employee has no significant marginal gain on the evacuation time. Is it still significant at 25 employees?

25 employees vs default: F = 0,46294, Fcrit = 4,182964. F < Fcrit, so the threshold is between 5 and 25 employees. Nice variable for further research.

Scenario 4 - alter the sighting distance 4 / 8 / 12 / 16

More or less smoke in the simulation, adjust sighting distance.

Disclaimer: a sighting distance (SD) of 4 resulted in an evacuation time of 500+ ticks, in all runs (12 quantities). A sighting distance this low just does not let the turtles find a guide, resulting in endless wandering and probably death. We took it out of our graphic representations because it makes no sense to graphically assess cases that all result in 500 ticks (our maximum).

When the sighting distance of the agents in the simulation is higher, we expected the evacuation time to be lower seeing as how the visitors who are looking for a guide would take longer to find one.

Sighting distance	**8**	**12**	**16**
Average	277,8	261,7	258,8
Standard Deviation	19,90	8,21	10,01
Nr of runs	10	10	10

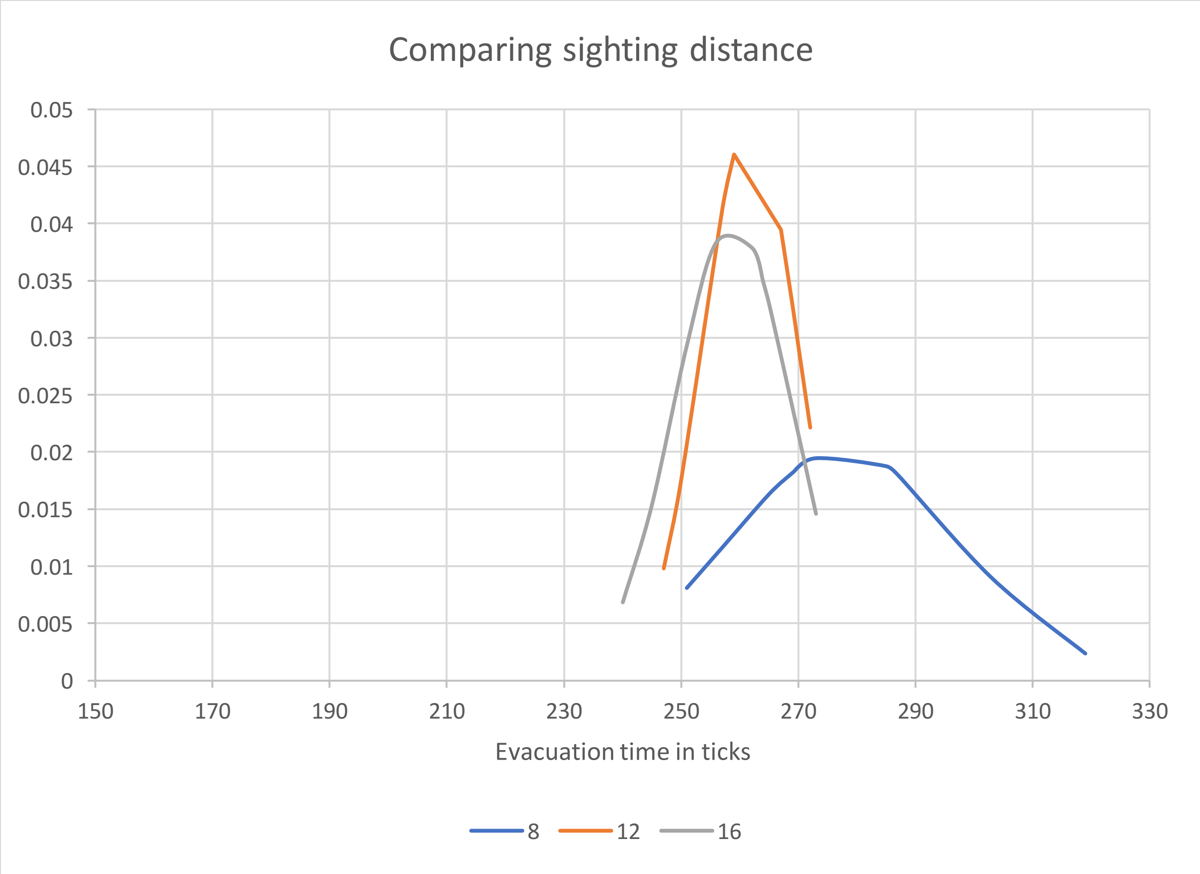
This was indeed the case, with a longer evacuation time than in the default settings when the sighting distance is shorter. When the sighting distance is 12, the evacuation time is already 6 ticks lower on average than in the default setting, en this gap becomes 9 when the sighting distance is 16.

F = 5,017987, Fcrit = 3,354131. F > Fcrit, so the null hypotheses is rejected. The variance between sighting distances differs.

SD 8 vs default: F < Fcrit, so no variance.

SD 16 vs default: F < Fcrit, so no variance.

The sigthing have no impact on the evacuation time (with 8<SD<16). As stated in the disclaimer, with a SD of 4, the model runs 500+ ticks. That variates enough from the default setting, but we think it is a fault in our model that no one can find a guide with SD = 4, were in reality this might be the case. Concluding, if we differ the SD very much from the default (10), there is a difference, but we blame it model malfunctioning instead of significant difference.



What is interesting is that the gap between 8 and 12 and 12 and 16 is much smaller. This can be explained by the fact that with a sighting distance of 12, the area of the cone of vision is already so big that most visitors who are looking for a guide will almost directly find one.

Scenario 5 – Only women or only men

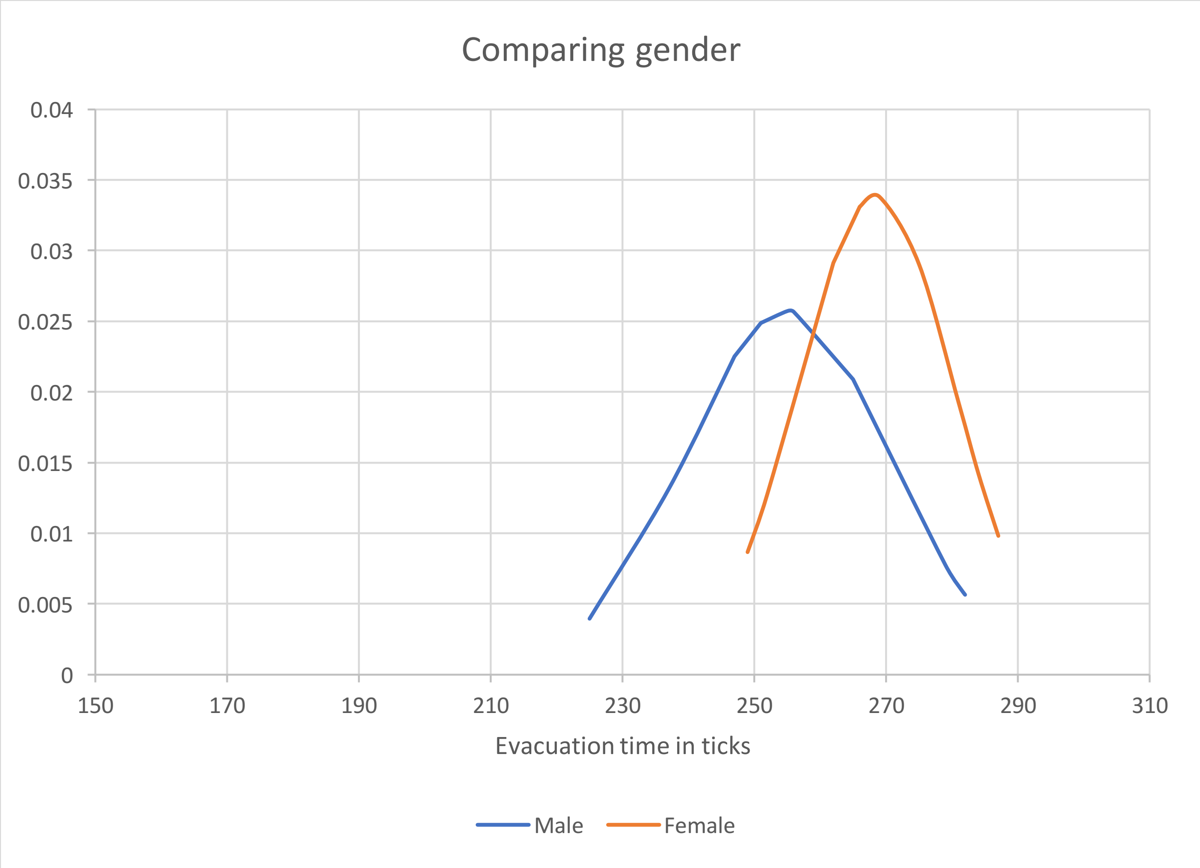
When the simulation is running with all agents being either male or female, we expected that the male simulation would be faster due to higher running speed.

	Male	**Female**
Average	255	268,45
Standard Deviation	15,52	11,80
Nr of runs	12	11

This assumption was also true, with the average evacuation time for men being 255 ticks which is 12 ticks lower than in the default situation. For women the average evacuation time was 268 ticks, 1 tick above the default situation.

In the scenario Males vs Females: F = 7,679288, Fcrit = 4,351244. F > Fcrit, null hypotheses rejected, males are faster than females.

Males vs default: F = 5,546098, Fcrit = 4,195972. F > Fcrit, Males are faster than the default. Gender has an impact on the evacuation time.



This shows that the women in the simulation slow the evacuation down significantly. This is due to fact that the different running speeds can cause congestion when there are too many agents on the same patch

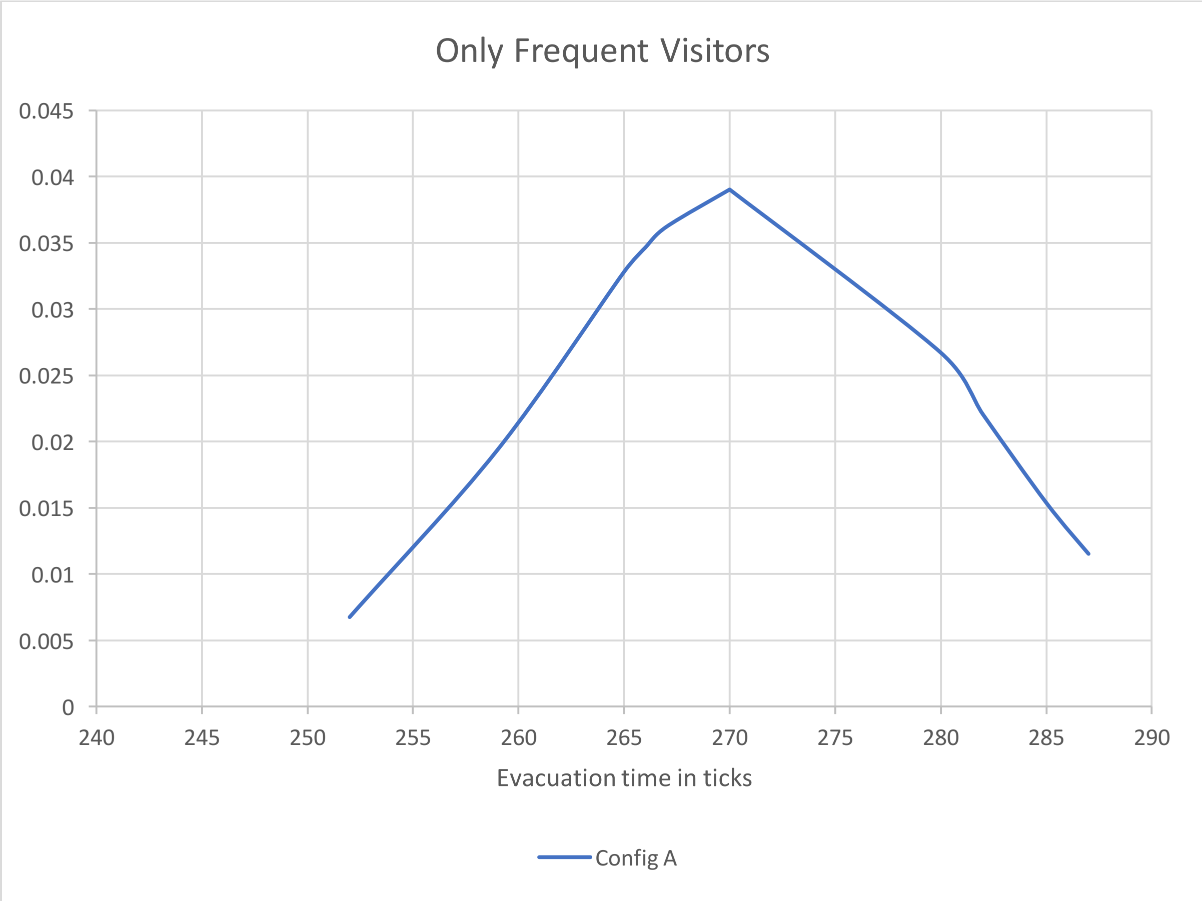
Scenario 6 – all frequent visitors

We expected that exit A was slower than all visitors know the nearest exit, and this was the case. It makes sense that when only one exit is in use, the evacuation time of a building increases. On the other hand, when all visitors know the nearest exit, they could escape the building faster, so this results in a large difference between the two scenarios.

	100% frequent visitors	**Default**	**Only exit A**
Average	271,1	267,2	328,3
Standard Deviation	10,16	10,83	20,62
Nr of runs	12	20	10

In the scenario Frequent visitors vs Only exit A: F = 65,01637, Fcrit = 4,351244. F > Fcrit, null hypotheses rejected, 100% frequent visitors faster than when only exit A is in use.

100% frequent visitors vs default: F = 0,946694, Fcrit = 4,170877. F < Fcrit, no variance in evacuation time between the scenarios.



Only Frequent Visitors
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
240
245
250
255
260
265
270
275
280
285
290
Evacuation time in ticks
Config A

6. Conclusions, Discussion & Recommendations

6.1 Conclusion

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?

The main entrance is exit A. From the experiment that answers the second research question we learned that the average evacuation time with only exit A available is high; 328,3 ticks. When the frequent visitor slide is set at 100, all agents know the nearest exit (employees already know the nearest exit). With the slider at 100, the average evacuation time is 271,1 ticks. As was seen in scenario 6, this is a significant decrease in evacuation time compared to only using the main exit, with a total difference of 57,2 ticks. We think that exit A is very slow due the fact that all agents bump into each other near exit A, reducing their movement speed non-linear. What is interesting, is the fact that 100% frequent visitors (all visitors know the nearest exit) result in no difference (no significant variance) evacuation time than the default setting, where there are visitors who don't know any exits or only exit A. We think that in the default scenario the frequent visitors and employees that are there, result in enough guidance for unknowing visitors, that there is no difference.

2. Systematically vary which exits all agents will exit the building through (only A, only B, only C, A or B, B or C, A or G, etc.).
    a. What are the differences in evacuation time?

Exit	A	B	C	A+B	A+C	B+C
Average	328,3	319,5	272,4	325,4	278,3	272,0

Apparently exit A is the most difficult exit to reach, resulting from the fact that exit B has a lower average and exit C is not even significantly different from the default (all three exits). This is also reflected in the second scenario where two exits were available. A+B is the slowest of the three, were as the scenario where exit C is open (A+C and B+C) are relatively fast. So as is seen from the single exit scenarios, exit A is the slowest and exit C is the fastest.

    b. How many times should you run each variation?

We ran each variation on the default 14 times, so that we could take out the model failures (500+ ticks) and still have more than 10 simulations per alteration. After consultation with the TA's, we concluded that 5 simulations sufficed, and to be sure we doubled that amount to at least 10. We ran the default scenario 20 times because we compare it with every other scenario, and we wanted to decrease the fault margin. With more repetitions we decrease the fault margin.

3. What is the difference in total evacuation time if there are signs in the building that lead the visitors to the nearest exit, compared to a building with no signs? Which assumptions do you need to make?

If there are signs in the building leading visitors to the nearest exit, we assume that every agent knows the shortest path to the exit. Therefore, to simulate a situation with exit signs, we ran a simulation 12 times where every visitor is familiar with all exits. The average time to escape is only 3.9 seconds faster when there are exit signs. According to the ANOVA test, this difference is not significant. An explanation for this is that in the default settings, agents who know all exits alert others near them of the nearest exit. Because this occurs every tick, most agents are quickly aware of the nearest exit.

4. How does gender or familiarity influence total evacuation time?

As is seen in the ANOVA test in scenario 5, there is a variance between the gender male/female. Males are significantly faster than females. With an average of –12,2 ticks on the evacuation time versus default, males are significantly faster than the default. Only females make no impact on the evacuation time. As is said, the difference is due to the running speed, which is faster for males. Besides that, we coded no further difference.

5. Which parameter influence response time most?

We provide two variables, where one has the most time increasing effect, the other the most time decreasing effect. Both variables differ significantly from the default, as was seen from the ANOVA tests described above.

With an extra 61,1 ticks, the scenario where only exit A is in use increases the evacuation time the most. This is particularly curious since the scenario where only exit C is in use has no significant impact on the evacuation time. The presence of only 5 employees in the library has the most decreasing effect on the evacuation time, with an average of –13,3 ticks versus the default.

6.2 Discussion

The first thing to point out is that this is a model, which is a computer implementation based on our assumptions of reality. Our assumptions are also inherently subjective, which means that at least to some extend the model is subjective to. Therefore, the results obtained from the model can never give a completely realistic view of reality.

Aside from the limitations due to our assumptions, there are also assumptions missing in the model. For instance, the children in the simulation are unaccompanied and are assumed to not know any of the exits. Therefore, if they can't find a guide they will continue to wander around and eventually die. While in reality, in the event of a dangerous situation, another adult would certainly take the child with them.

Another element of the model is that people who don't know any exits keep on wandering around until they find a guide. While in reality, people who don't know any exit will likely follow everyone they see.

Furthermore, we used the sighting distance in the simulate smoke, yet in the model we still act like all employees will know exactly where to go. Yet in a room full of smoke, it could well be that the employees don't know the precise location of the exits anymore. Another limitation of the model is that the field of view of the agents can see through walls. Therefore, the agents who don't know any exits will find a guide much faster that in reality.

Furthermore, some of the parameters such as the smoothness might impact the accuracy of simulation. As this parameter constantly resets the path of the agents, while in reality they would likely stick to the path they are on.

6.3 Recommendations

Regarding the Model

There are several improvements that can be made to the model, that would both positively influence the evacuation time and the credibility of the model's representation of reality. First of all, the limitations discussed above can be corrected in the model, making it a more precise display of reality.

Another element that could be added to the model, is a representation of actual danger in the form of a fire or smoke. It would be interesting to see how this would change the behavior of the agents in the simulation, and to see its effect on the evacuation time.

Furthermore, to be able to draw better conclusions the amount of runs of the different experiments could be increased. This would make the results more robust and therefore reliable.

Regarding the Safety of the Library

With respect to the safety of the library, our results indicate that especially exit C is important for the evacuation of the library. This is likely because it is located near most of the small rooms at the bottom of the floorplan. Considering that it is not the main exit, and it is therefore likely that not all visitors of the library are aware of its location, we recommend to clearly indicate the shortest route to it in the bottom of the floorplan. These exit signs are also important in case there is a lot of smoke, considering this can have a disorientating effect on the people inside the library, and when the sighting distance became too short, a lot of people remained stuck in the model.

Another countermeasure the TU delft could take against the disorientating effect of smoke, is to make sure the library is fitted with good ventilation. This could counter act the bad visibility caused by the smoke.

Furthermore, we recommend to offer fire safety instruction to the visitors of the library, to maximize the number of visitors aware of all exits.