Comparing Evacuation Strategies for the Bernoulliborg Ground Floor

Agent Technology Practical Group 2

Amelie Astruc (s4306589), Cristina Ropot (s4279956),
Amanda Komulainen (s4242807), Peter van den Bempt (s4377400)

April 7, 2023

1 Introduction

1.1 Topic

Fires are among the most common emergencies that may happen inside buildings. Besides building damage, fire can lead to casualties if an evacuation plan is not thoroughly established. According to the International Association of Fire and Rescue Services, there were 79560 fires in the Netherlands alone in 2016, which has led to a total of 42 casualties "C.T.I.F.", 2016. Due to this reason, prevention and handling of such cases is essential.

Harmful scenarios can be assessed before their occurrence by simulating them in agent-based models (Kasereka et al., 2018; Ren et al., 2009; Trivedi & Rao, 2018). Siyam et al. (2020) stated that evacuation drills are traditionally used to evaluate evacuation. However, agent-based models are more cost-effective and potentially more accurate. Using an agent-based model can lead to valuable insights and observations, thus allowing us to determine the best procedure for a swift and safe evacuation with minimal resources. For example, Trivedi and Rao (2018) used agent-based modelling to identify specific bottleneck locations in simulated environments. Agent-based models have also found that increased evacuation speeds lower the evacuation efficiency (Ha & Lykotrafitis, 2012; Ren et al., 2009). Additionally, Chen and Zhan (2008) investigated the difference in efficiency between simultaneous and staged evacuation and found that the efficiency of their strategies depended on the specific environment in which they were tested.

1.2 Innovation

The Dutch law on working conditions states that adequate measures must be implemented in case of potential emergencies, such as fires. One of the most critical elements they require is a quick evacuation of people present in the building ("Arbeidsomstandighedenwet" (2023)). Kuligowski and Kuligowski (2005) compared and evaluated 25 current computer evacuation models and concluded that the best evacuation model depends on the situation and specifics of the event. Inspired by this, we chose to use agent-based modelling in *Netlogo* to implement the evacuation of the ground floor of the Bernoulliborg (BB) building by using multiple evacuation strategies. We chose the ground floor as it is one of the most saturated floors with students and employees due to the large study area, the cafeteria, and the student association/office room. Therefore, the main innovation of our project is the evaluation of multiple strategies within the same specified environment. This testing allows us to eliminate certain confounding variables we would have had to deal with otherwise. For example, Ha and Lykotrafitis (2012) proposed that there exists an effect of the complexity of building architecture (such as multi-floor or multi-room buildings) on emergency evacuation processes. Keeping the environment constant on the ground floor allows us to assess each evacuation strategy reliably.

2 Methods

We are taking inspiration from the findings of Chen and Zhan (2008) and aim to investigate the effectiveness of three common strategies, namely *Random Evacuation, Staged Evacuation* and *Directed Evacuation*. We modelled the evacuation processes in an environment based on the Bernoulliborg ground floor to assess these different strategies. The model is built in *NetLogo*, a programming language that allows multi-agent modelling and experiment simulations. The effectiveness of these strategies will be measured by considering the time it takes for the evacuation to be completed and the number of casualties at the end of the evacuation.

2.1 Conceptual model

The model uses a manually built world that matches the layout of the Bernoulliborg ground floor. We assume that all agents will follow the chosen strategy, which simulates a scenario where individuals in the building are fully informed of the evacuation plan. This model also assumes a real emergency where the hazard is included; hence a spreading fire within the building was implemented. The evacuation strategies implemented, as mentioned earlier, are *random*, *directed*, and *staged* evacuations.

The *random* evacuation strategy was implemented by allowing the agents in the model to choose their exits randomly based on their location. This strategy simulates a scenario where an evacuation plan is not instilled; individuals are panicked, and rational thoughts are inhibited. Although the exits are chosen randomly, the list is predetermined based on the agents' location to simulate a degree of rational thought process. Based on our intuition, individuals would still choose the closest exit they can perceive or are aware of in a case of emergency. The *random* evacuation strategy was chosen to show the contrast in efficiency between a well-defined plan, such as the *directed* and *staged* strategies, and an arbitrary plan.

The *directed* and *staged* evacuation strategies are chosen based on the study by Chen and Zhan (2008), who looked at the efficiency of these two evacuation plans in an urban setting. In the *directed* evacuation strategy, agents are assigned exits designed explicitly for their location. In this scenario, individuals know the nearest, proper emergency exits. The *staged* evacuation strategy simulates a process where individuals within the vicinity of the fire will be given priority to evacuate before progressively evacuating individuals further from the fire. In this strategy, the agents are also aware of their location's designated exits. Regardless of the strategy, all agents must consider obstacles in their surroundings, such as walls, tables, staircases, and other agents, that affect their speed and trajectory. Agents must also actively avoid spreading fire, head towards their chosen exit given the strategy, and change exits if their designated exit is blocked.

2.2 Implementation details

In this model, the user can manipulate the following parameters:

- Evacuation strategies, namely:
  - Random Evacuation
  - Directed Evacuation
  - Staged Evacuation
- pen-yes (turtle pen)
- num-agents
- spread-rate
- crowd-factor

Where **spread-rate** affects the spreading of the fire, and **crowd-factor** affects the speed of agents in crowds. The **pen-yes** is an optional parameter that draws the path of movement behind each agent.

2.2.1 Environment and Initialization

To build the environment, we first imported an image of the floor layout to *Netlogo*. Based on this image, we recoloured the patches on the *Netlogo* environment using patch coordinates to match the lines in the layout. This is how we achieved the base layout, which includes the wall lines, staircases, and exit door locations. In the next step, we added obstacles by estimating the locations of the tables within the cafeteria and the study area from real-life references. We represented these obstacles as black squares the agent cannot go through.

Adding obstacles in the larger rooms was necessary because a large empty space would ease the evacuation process beyond what is realistic. The smaller office rooms and bathrooms were omitted in our implementation, as we assume individuals in the private office rooms and bathrooms can exit them swiftly. We made an exception for the student association/office room (grey) due to the larger population presence in the room, as exiting the room would not occur as smoothly with more people in it.

Each location are color coded by repainting the area of each location with a different color. Colouring the locations allows a more manageable method to configure the experiment setup, such as setting the agents in the building, assigning the designated exits per location, and starting the fire from within the building. Instead of keeping track of coordinates for each location, we can use patch colours to determine the areas on the map.

- Cafeteria (pink)
- Study landscape (blue)
- Hallway (yellow)
- Student association room/office (grey)
- Lobby (green)

The exit doors are also set with different shades of red for the same reason. The environment layout is generated by the **Build World** button in the interface and only needs to be created once. The world layout and interface can be observed from Figure 4.

Individuals are represented as turtles and spawn on random patches within the building at **setup**. The student association/office room spawns fewer turtles as it is the smallest room on the map. Before the model can run, the evacuation strategy must be chosen first, as it will set the exit for each turtle. The exit determines the direction each turtle will face and consequently affects their trajectory, so it is crucial to set the strategy before running the model. Otherwise, the model will not run at **go**.

2.2.2 Evacuation Process

At **go**, the turtles will start moving towards their assigned exit with a constant speed of 1. The speed will decrease once the turtle encounters other turtles in its vicinity. If the chosen strategy was *staged*, only the turtles within a radius of 70 to the fire will start moving. This radius value was chosen arbitrarily; however, from observation, this value was most appropriate relative to the floor layout to ensure that only the nearest turtles would evacuate first.

The turtles own a variable **in-office?** that is used to check whether they reside inside the student association/office room. Using this variable, we ensure that the turtles first prioritize leaving the room, and once they do, they will face the designated exit again. If the patches ahead (within two

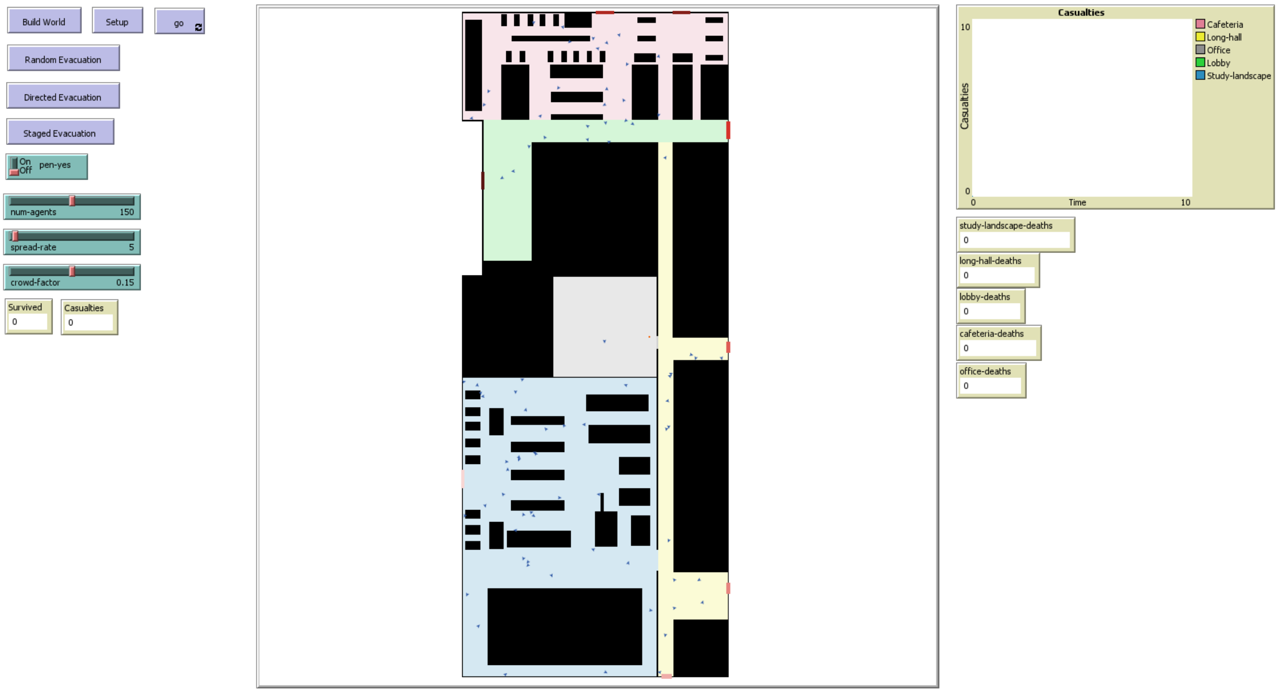

Figure 1: Layout of the Bernoulliborg Ground Floor in *Netlogo*

patch distance) of the turtle are black or orange, meaning the patches make up an obstacle or fire, the turtle will backtrack and move towards an arbitrary direction to avoid it. If all of the patches ahead are orange (within three patch distance), the turtle will deem the path blocked by fire and change its exit. The evacuation process continues until all alive agents exit the building.

2.3 Experimental setup

A goal of our experiment was to keep it as concise as possible while also gathering informative data. This is why we chose only to manipulate the strategy types while leaving the other parameters constant. In order to run our experiments, we used the *BehaviourSpace* tool that *Netlogo* provided us with. To start with the experiment, we set up the following parameters with fixed values for every strategy:

- num-agents
- spread-rate
- crowd-factor

For the experiment, we turned the pen parameter off. The number of agents was set to 150, the spread-rate of fire was set to 5, and the crowd-factor was set to 0.15. We then ran the model 40 times for each strategy. The number of casualties and evacuation time was recorded and stored. Furthermore, the casualty rate per area was computed. To do so, we first counted the number of agents present in each region at the start of the evacuation. Using percentages, we then recorded how many of those agents died per region. The averages of the above measures were analysed using Kruskal-Wallis and Dunn tests.

3 Results

3.1 Casualty Rate

Figure 2 displays the mean casualty rate for each strategy, measured over 40 runs. The mean casualty rate (in percentages) was the lowest for the *directed* strategy, closely followed by the *random*

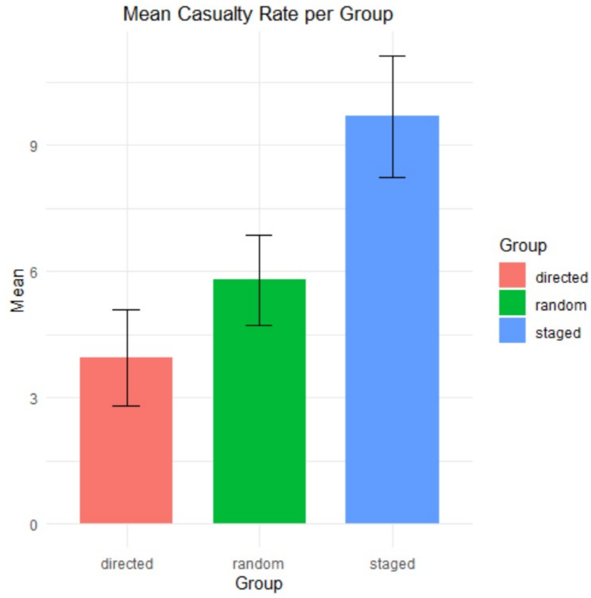

Figure 2: Mean casualty rate per group in percentages. Error bars indicating ±1.143, ±1.077 and ±1.452 standard error, respectively (from left to right)

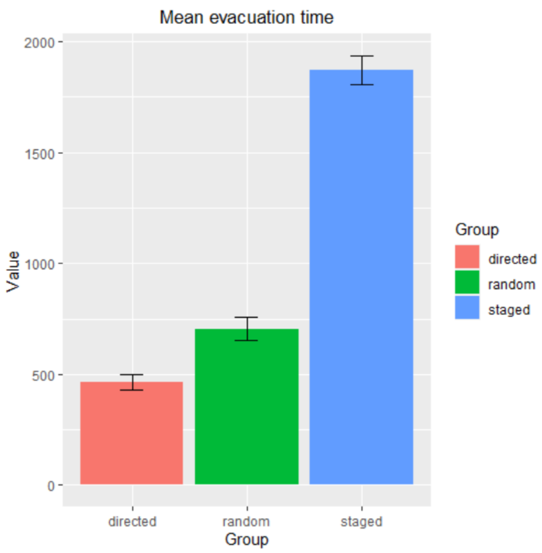

Figure 3: Mean evacuation time per group in ticks. Error bars indicating ±35.30, ±51.47 and ±65.83 standard error from left to right.

strategy. The *staged* strategy had a much higher mean casualty rate.

A Shapiro–Wilk test showed that the data was not normally distributed (p = 2.117e-13). Therefore, we performed a Kruskal–Wallis test and found a significant mean difference between the three strategies (p = 0.0001). A further post hoc Dunn test (with Bonferroni correction) showed that the *staged* strategy had a significantly higher casualty rate compared to the *directed* (p = 0.0000) and *random* (p = 0.0453) strategies. The difference between the *directed* and *random* strategies was insignificant (p = 0.0557).

3.2 Evacuation Time

Figure 3 shows the mean evacuation time per strategy, measured over 40 runs. The time was measured using the number of ticks until the last agent in the building was either safe or dead. The mean evacuation time was the lowest for the *directed* strategy and slightly higher for the *random* strategy. Once again, the *staged* strategy performed much worse.

Again, the data were assessed with a Shapiro–Wilk test and found that they were not normally distributed ($p = 8.275e\text{-}09$). A Kruskal–Wallis test showed that there was a significant difference between the three groups (p-value $< 2.2e\text{-}16$). We performed a post hoc Dunn test with Bonferroni correction. Unlike our previous comparison, there was a significant difference between all three strategies. The *directed* strategy was faster compared to the *random* strategy ($p = 0.0063$). The *staged* strategy fell behind compared to both other strategies ($p = 0.0000$)($p = 0.0000$).

3.3 Area Safety Comparison

In Figure 4, we aggregated the data from all three strategies and compared the mean death rate per area over 120 runs. Once again, the data were not normally distributed, so we used non-parametric test. A Kruskal–Wallis test determined that the means were dissimilar ($p = 4.465e\text{-}06$). Upon further analysis, a Dunn test with Bonferroni correction showed that only the cafeteria had a significantly different mean casualty rate compared to the other areas ($p = 0.0000$, $p = 0.0034$, $p = 0.0046$, $p = 0.0064$ for the office, long hall, study landscape and lobby, respectively).

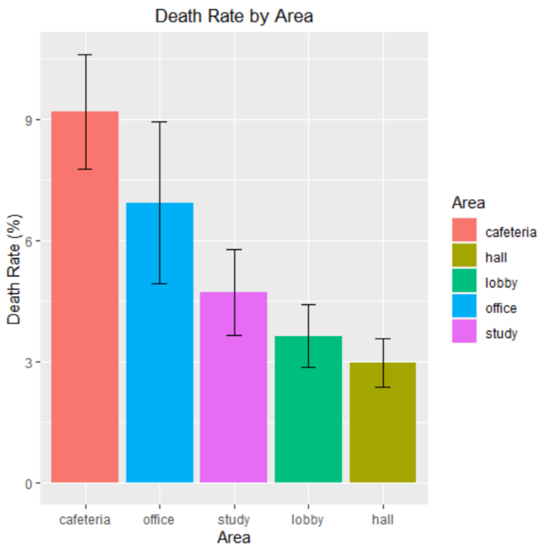

Figure 4: Mean death rate per area. Error bars indicating ±1.4289, ±2.0074, ±1.0579, ±0.7683 and 0.5949 standard error from left to right.

4 Discussion

4.1 Strategy interpretation

Our research assessed different evacuation strategies within the same specified environment; the ground floor of the Bernoulliborg building. As shown in the results section, we performed Kruskal-Wallis and Dunn post hoc tests on our data. We conclude that the *directed* strategy's evacuation time was significantly lower than the other strategies. Furthermore, the casualty rate for the *directed* strategy was significantly lower as well compared to the *staged* strategy, but not compared to the *random* strategy. Additionally, we found that the casualty rate in the cafeteria was significantly higher than in other areas of the building, implicating relative danger.

In our implementation of strategies, we chose to model the *staged* strategy in the same way as the *directed* one, except for the fact that the agents closest to the fire start evacuating first, instead of all agents at once. As our results indicate, this small change does lead to a significant difference, but this is not to say that this sort of shortcut is the best implementation. We would, therefore, be interested in modeling there two strategies differently in order to see what results we would then get.

Here, we've discussed the implications of significant differences between strategies, but we have not discussed what the insignificant differences can tell us. By observing an insignificant difference between the *directed* and *random* strategies, we are led to believe that this is because the ground floor of the Bernoullibourg is well designed in terms of evacuation architecture. Meaning the number and placements of exit doors are well thought of and efficient. Of course, this is not the only reason that could lead our results to be insignificant.

In the next section, we will assess how valuable these findings are by evaluating our model.

4.2 Potential problems and validity

We recognize that our measures strongly depend on the fire's starting location, which is a critical confounding variable. When the fire started in the hallway or office, the number of casualties was lower than if the fire started in the cafeteria, lobby or study landscape. This might have affected our results even though we did 40 repetitions. A different approach could be to select multiple fixed starting locations for the fire and evaluate the strategies based on their performance for each starting location.

Another potential problem in our research could be that we did not base our parameters on empirical data. The spread-rate of fire is a complex factor that is influenced by many variables that are specific to the event of the fire itself. Due to the lack of empirical data for this parameter, especially for the Bernoulliborg building, we had to resort to our own approximations. One way we could tackle this issue is to find existing literature on the default spread rate of fire relative to the speed of humans, and improve the accuracy of our model.

In *NetLogo* intelligent behaviour of an agent is difficult to model. For instance, the further an agent can see, the slower the model becomes. In our model, our agents have an abstraction in their movement. When they bump into a wall or fire, they turn around and suddenly speed up. They would check whether or not they could move there, however. This sudden increase in speed is a complicated behaviour that we cannot justify fully. Although, the sudden increase in speed was necessary for the model to function well. Humans would not move towards the fire in the first place. When evacuating, human behaviour would compose different solutions, not just one, and then compare and evaluate which is best. This all happened in just a tiny amount of time. The full implementation of human decision-making would be incredibly complex in *Netlogo*. We predict a trade-off between realism and the amount of data that can be generated. For example, a 3D physics-based evacuation model might be able to fit empirical data better but might make it difficult to gather a reasonable amount of data to compare.

4.3 Future research

We recorded our casualties by measuring the number of agents that came into contact with fire. However, "Fire Safety and Burns", 2023 found that most casualties during evacuation when a building is on fire are due to smoke inhalation. The toxic gasses produced by fires are accountable for about 30% fire-related deaths and injuries. Smoke moves vertically and horizontally through the air while trapping any air in the corners and crevices of rooms ("How Does Smoke Spread?", 2021). In our research, we did not include the spread of smoke. Further research could examine the effect of smoke on the efficiency of evacuation strategies. With the addition of smoke, evacuation time might become a more useful measure of building safety.

Based on the analysis of floor plans, the evacuation of other buildings on the RUG Campus, such as the Linnaeusborg, might also produce interesting findings when modelled using an agent-based model. In particular, the Linnaeusborg has a more tangled network of rooms and areas than the Bernoulliborg. In a hypothetical future project, we could transfer our current evacuation dynamics and behaviour to multiple buildings to compare them and highlight dangerous areas.

Lastly, the spreading of fire in the Bernoulliborg building is relatively controlled by fire doors. Fire doors close the moment that the fire alarm goes off. Those fire doors limit the spreading of fire by cutting the new oxygen supply, which would slow the growth of a fire ("What is the purpose of a firedoor?", 2021). Fire doors could protect escape routes, affecting the most efficient and safest evacuation strategy evaluation. Our model could be expanded by including fire doors and the limitation of spreading fire.

5 Division of labor

5.1 Amanda

Environment layout, code, report, presentation

5.2 Amelie

Report, presentation, sources

5.3 Cristina

Sources, report, presentation

5.4 Peter

Report, code, statistics, graphs, presentation

References

Arbeidsomstandighedenwet. (2023). `https://wetten.overheid.nl/BWBR0010346/2011-04-01`

C.t.i.f. (2016). `https://www.ctif.org/world-fire-statistics`

Chen, X., & Zhan, F. B. (2008). Agent-based modelling and simulation of urban evacuation: Relative effectiveness of simultaneous and staged evacuation strategies. *Journal of the Operational Research Society*, *59*(1), 25–33. `https://doi.org/10.1057/palgrave.jors.2602321`

Fire safety and burns. (2023). `https://www.stanfordchildrens.org/en/topic/default?id=fire-safety-and-burnsinjury-statistics-and-incidence-rates-90-P02978`

Ha, V., & Lykotrafitis, G. (2012). Agent-based modeling of a multi-room multi-floor building emergency evacuation. *Physica A: Statistical Mechanics and its Applications*, *391*(8), 2740–2751. `https://doi.org/https://doi.org/10.1016/j.physa.2011.12.034`

How does smoke spread? (2021). `https://www.fireprotectiononline.co.uk/info/how-does-smoke-spread/`

Kasereka, S., Kasoro, N., Kyamakya, K., Doungmo Goufo, E.-F., Chokki, A. P., & Yengo, M. V. (2018). Agent-based modelling and simulation for evacuation of people from a building in case of fire [The 9th International Conference on Ambient Systems, Networks and Technologies (ANT 2018) / The 8th International Conference on Sustainable Energy Information Technology (SEIT-2018) / Affiliated Workshops]. *Procedia Computer Science*, *130*, 10–17. `https://doi.org/https://doi.org/10.1016/j.procs.2018.04.006`

Kuligowski, E. D., & Kuligowski, E. D. (2005). *A review of building evacuation models*. U.S. Dept. of Commerce, National Institute of Standards; Technology.

Ren, C., Yang, C., & Jin, S. (2009). Agent-based modeling and simulation on emergency evacuation. In J. Zhou (Ed.), *Complex sciences* (pp. 1451–1461). Springer Berlin Heidelberg.

Siyam, N., Alqaryouti, O., & Abdallah, S. (2020). Research issues in agent-based simulation for pedestrians evacuation. *IEEE Access*, *8*, 134435–134455. `https://doi.org/10.1109/access.2019.2956880`

Trivedi, A., & Rao, S. (2018). Agent-based modeling of emergency evacuations considering human panic behavior. *IEEE Transactions on Computational Social Systems*, *5*(1), 277–288. `https://doi.org/10.1109/TCSS.2017.2783332`

What is the purpose of a firedoor? (2021). https://www.thefpa.co.uk/advice-and-guidance/advice-and-guidance-articles/what-is-the-purpose-of-a-fire-door-