The Impact of Human Behavior in Emergency Evacuations

Francisco Sena
Joana Alves
João Palet

1 INTRODUCTION

The evacuation of people from a building on fire is a task which can prove to be very difficult, in particular because of the influence of human behavior [2], but also of the type of people or the evacuation place configuration. In this work we will study some relevant factors in that regard, focusing more on two things: the impact of cooperative communication and risk-prone versus risk-averse policies of the evacuees. The quality of a configuration will be evaluated by the average value of relative survivors over all the performed simulations with that specific configuration. We begin by explaining our multi-agent system and then move to the architectural principals of our agent "evacuee". We conclude with an extensive experimental analysis of our simulations.

2 AGENT SYSTEM AND EVALUATION

2.1 Model

We propose for consideration the following agents:

- Evacuee: agents of this type represent the people inside the building. Each of these possesses a set of characteristics: health, visual acuity, some object that describes its risk-seeking level, and disposition for communication.
- Fire: represents the fire.
- Smoke: represents the smoke created by the fire.
- Alarm: represents the fire alarm.

The agents interact in a bi-dimensional grid. That grid is a mere representation of the layout of the building. At each time step, every cell (except the exits) is at most occupied by one agent. When an evacuee agent reaches the exit we simply remove it from the environment and count him as a survivor.

Before diving in a more detailed explanation of our model, we will clarify all the accorded assumptions. The fire starts at the beginning of a simulation at a random position in the building. Although this may not be very realistic, since in principle some areas of a building have more probability to start a fire then others, we hope to make up for this imperfection with a high number of runs in our simulations. We defined that fire creates smoke in its neighbourhood, and both of them propagate at a well defined speed, not necessarily equal. The reason for that is simply to encode the fact that fire is always accompanied by smoke. We also assumed that the evacuees never consider moving to a cell with fire.

Evacuees may have different personalities regarding their predisposition to take risks with some being more prone to it and others more conservative, or maybe even have different endurance level. For instance, if an evacuee is confronted with smoke when pursuing some path, it can either cross it or change its mind and look for a clearer path although a bit longer than the first. To address this specification, each evacuee computes the path to some exit that minimizes its cost. We will explore this idea in more detail later on, in particular, how we calculate the cost of a path. The evacuees will also be able to communicate with each other in some well defined range, by exchanging information about their beliefs of the environment in hope of increasing their chances of survival. With the purpose of modeling a more realistic human behavior, the evacuees spawn in random positions at the beginning of the simulation and will be moving randomly over the environment until they perceive any source of danger, e.g., seeing smoke, seeing fire, hearing the alarm or being informed by another evacuee that a fire had begun. Although the evacuees know with certainty the layout of the building, the environment is not fully accessible since they cannot know, at every given time step, the position of the fire, smoke and other evacuees on positions out of their range. Regarding the fire and the smoke, we defined that both deal damage to the evacuees with the particularity that fire deals much more damage than smoke.

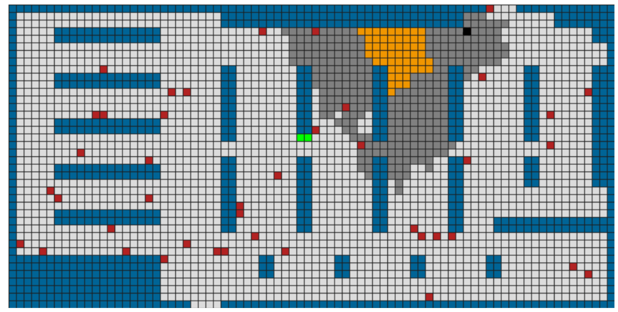

Figure 1: The environment. The blue cells correspond to walls, red to evacuees, orange to fire, grey to smoke, and black to evacuees that did not survive. The green cells correspond to alarms before going off, and will turn bright red after going off. The exits are on the top right corner and bottom left corner.

2.2 Architecture

The main focus here goes to the evacuees, which are deliberative agents that contain an explicitly represented model of the environment encoded by a bi-dimensional array and make decisions on which actions to perform via practical reasoning. Their main and only goal is to leave the building alive and, to achieve it, they plan their actions using means-to-end reasoning. Given the known exit points, the current state of the environment according to the agent's beliefs and the set of possible moves, i.e., up, down, left

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and right and their predisposition to take risks, the agents can elaborate a plan containing the set of actions that, at that moment in time and according to their beliefs, can lead to them leaving the building alive. Evacuees are also open-minded agents, since they only maintain their intentions until they are achieved or still desired, reconsidering their current plan every time their model of the environment is updated, whether by seeing something new within their vision range or by being informed by other agents.
This way, the evacuees' decision making loop consists in perceiving the state of the environment around them, communicating it to other agents if they are near enough, using means-to-end reasoning to find a new escape plan if their beliefs were updated and, finally, executing the first action of the plan.

2.3 Implementation Details

In this section, we will highlight some relevant implementation details and introduce some definitions, since these have a direct impact on the logic of our simulation and, consequently, the experimental results.

2.3.1 Fire propagation. Every 2 time steps, each fire cell randomly selects an adjacent cell to propagate to. If the selected cell is already on fire, nothing is done. If not, fire is then propagated into that cell with a given probability, which increases if the selected cell already has smoke in it.

2.3.2 Smoke propagation. There are two ways in which the smoke is propagated. Every time step, each fire cell randomly selects an adjacent cell. If that cell is free, smoke is propagated into the cell. Also every time step, each smoke cell propagates smoke to all of its adjacent free cells with a given probability.

2.3.3 Collisions between evacuees. It could happen that two agents move to the same cell at a given time step. To avoid such unrealistic scenarios, before moving, each agent calculates the cell he wants to move to. If the cell is free and no other agent plans to move there, the move is taken. If any other agent plans to move to the same cell, the agent with lower identifier moves first and the other agents wait until they can take the move.

2.3.4 Communication between evacuees. Within a given communication range, communicative evacuees can share information about their beliefs of the environment. Evacuees within the communication range will update their beliefs on any cell as long as the information they received is newer than the one they had for each specific cell.

2.3.5 Alarm. As soon as fire or smoke reach an alarm cell, every alarm on the building will start ringing and every evacuee who had not yet been alerted will start its evacuation.

2.3.6 Path calculation. Evidently, the main goal of the evacuees is to escape the fire. With that in mind, one could simply compute a BFS (Breadth-First Search) and get a tree of the shortest paths of the grid starting at the evacuee's position, considering only as valid cells to move the ones that are either empty or have smoke in them according to its beliefs. Indeed we could stop the BFS when we find the first exit. The problem of this approach is that it is hard to encode the behavioral discrepancy between evacuees that are risk prone and those that are risk averse, since all the evacuees will ignore the smoke when deliberating, and so, they will all behave the same. Taking that into account and adding flexibility to that argument, we used Dijkstra's shortest paths algorithm [1] where the cost of each transition varies if the evacuee is risk prone or not. We defined that, for all evacuees, the cost of transitioning to an empty cell is simply 1. Note that a risk prone evacuee will be more comfortable to move to cells with smoke, whereas a risk averse evacuee will tend to avoid those cells, since its more conservative with its health points. Therefore, for risk prone evacuees, the additional cost of moving to such cells is 0, and for risk averse evacuees the additional cost is 1. For efficiency purposes, the evacuees only re-plan if their beliefs of the environment were altered.

2.4 Control parameters

To allow for flexibility and a more fine grained study regarding the impact of different factors in the success of a evacuation, our implementation has many free parameters. In this section we explain their meaning and why they are relevant.

- VIS_RANGE: bounds the vision of the evacuees, i.e. how further ahead an evacuee is able to perceive its surroundings. Higher the range, higher the depth of perceptiveness.
- VOL_RANGE: bounds the communication capabilities of the evacuees, i.e. the range of the sound of their messages.
- $HEALTHPOINTS$: represents the health of the evacuees. It's a way of representing resistance to averse situations such as inhaling smoke.
- $FIRE$: controls the speed at which the fire spreads.
- $SMOKE$: controls the speed at which the smoke spreads.
- $FIRE\_DMG$: numeric value by which the health of the evacuees is reduced when standing in a cell with fire.
- $SMOKE\_DMG$: numeric value by which the health of the evacuees is reduced when standing in a cell with smoke.
- NUM_AGENTS: the number of living evacuees.

3 EXPERIMENTS

3.1 Metrics and Expectations

To assess the quality of a specific configuration while trying to minimize the influence of randomness in our results, we ran the simulation 100 times and computed the average of the percentage of survivors over all those simulations. All the experimental analysis will be based solely on that metric. Considering the characteristics of the layout, it's expected that if the building is equipped with an alarm the number of survivors will increase. Adding more exits to the layout will also result in a more successful evacuation.

It is expected that if we thoroughly increase the number of evacuee agents, the percentage of survivors will decrease. Some possible justifications for that can be the reduced amount of empty cells and the presence of clusters due to the large amount of people that is trying to escape the building in case of fire. With respect to the characteristics of the evacuees, we hope that enabling communication and increasing the vision and volume range will all contribute independently to a more successful evacuation. Regarding the behavioral aspect, we think that the chances of survival of a risk-prone evacuee opposed to a risk-averse evacuee will essentially be a coin flip. Risk-prone agents get burned more often on average than risk-averse agents because they consider a cell with smoke the same as an empty cell in terms of costs, but note that cells with smoke have a higher probability of igniting later on. Not only that but also simply because they prioritize shortest paths over clearer paths regardless of the properties of that path. Risk-averse agents spend more time on average inside the building and consequently die from inhaling smoke more often than risk-prone agents.

To illustrate this line of thought, observe **Figure 2**. If we consider the evacuee agent as a risk-prone one, it will move upwards until it reaches the exit since it is the path with minimum cost, and the cost of that path is 6. On the other hand, if we consider it to be a risk-averse evacuee agent, it will essentially try to go around the smoke with a path cost of 8, instead of following the risk-prone evacuee agent path which has a cost of 10 for the risk-averse evacuee. It becomes clearer now that it may happen by pure chance that the risk-prone evacuee dies from the fire and the risk-averse evacuee escapes or the risk-prone evacuee escapes and the risk-averse evacuee forces a path that is too long and may eventually die from standing in cells with smoke for too many time steps.

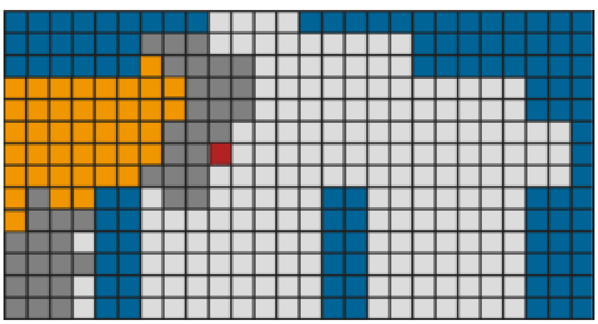

Figure 2: A possible scenario during the evacuation.

3.2 Simulation Results

For the following simulations, the layout used was the one present in **Figure 1**, which resembles a supermarket. A baseline with default values for the control parameters of the model was also defined and only the values of the parameter being tested were changing. These baseline values are the following:

- $VIS\_RANGE = 5$
- $VOL\_RANGE = 5$
- $HEALTHPOINTS = 100$
- $FIRE = 1$
- $SMOKE = 0.3$
- $FIRE\_DMG = 50$
- $SMOKE\_DMG = 2$
- $NUM\_AGENTS = 50$

As expected, it can be seen in **Figure 3** and **Figure 4** that the percentage of survivors increases, although not dramatically, when either the vision range or the volume range increase. This happens

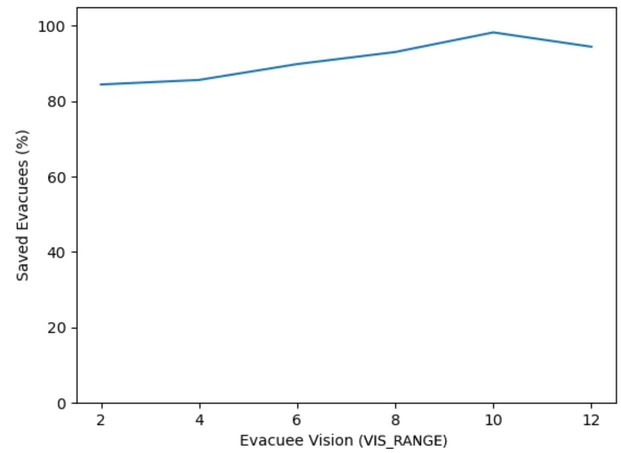

Figure 3: Influence of the evacuee vision range on the percentage of saved evacuees.

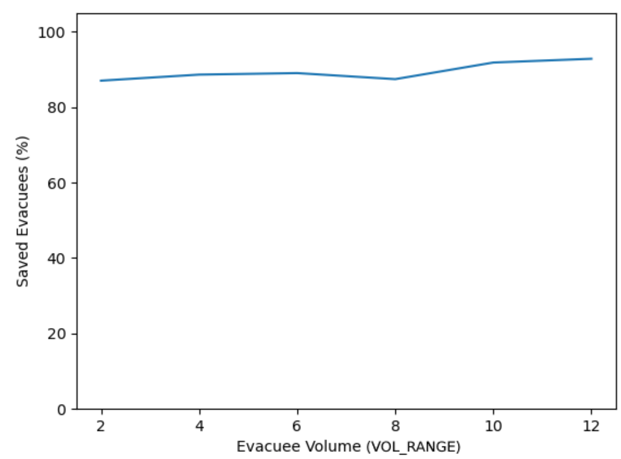

Figure 4: Influence of the evacuee volume range on the percentage of saved evacuees.

because the bigger the area around them that the evacuees can perceive, the richer their model of the environment is, which is a crucial factor for a successful evacuation.

The simulation presented in **Figure 5** regarding the influence of the percentage of risk-prone agents was run with 50% of communicative agents, while the simulation in **Figure 6** regarding the influence of the percentage of communicative agents was run with 50% of risk-prone agents.
To better assess the influence of parameters such as vision and volume range, both of these simulations were run without the presence of alarms in the building.

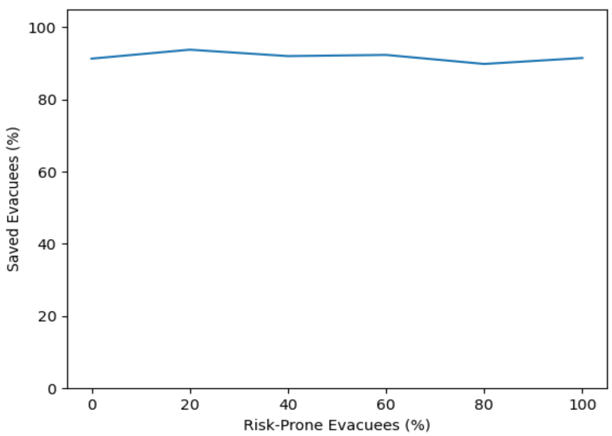

Figure 5: Influence of the percentage of risk-prone evacuees on the percentage of saved evacuees.

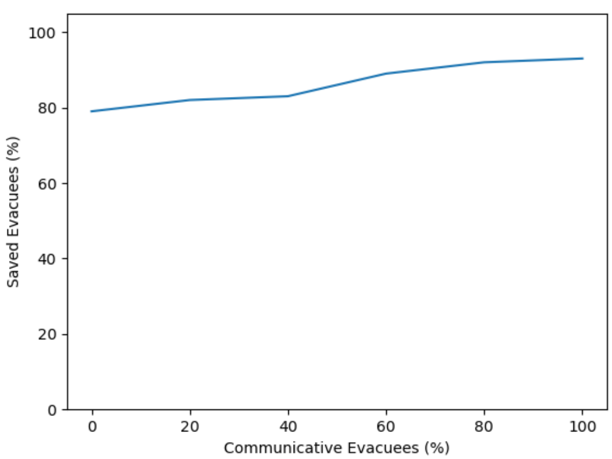

Figure 6: Influence of the percentage of communicative evacuees on the percentage of saved evacuees.

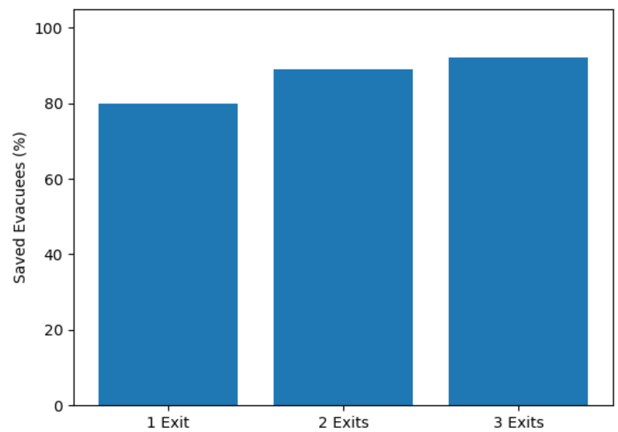

Figure 7: Influence of the number of exits on the percentage of saved evacuees.

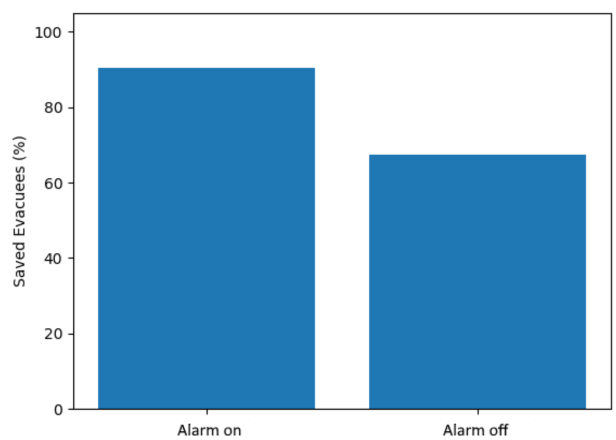

Figure 8: Influence of having an alarm on the building on the percentage of saved evacuees.

Regarding risk-prone vs risk-averse behaviour, it can be seen by the results that this is not a critical factor in the percentage of survivors. What this means, according to our model, is that evacuees who are more prone to risk, i.e., being more prone to assume paths that, although shorter, have more smoke in them, have similar survival rates to those who are more conservative and tend to prefer longer but clearer paths when they're available.

We have noticed that as we increase the number of exit doors, the number of survivors also increases. This simulation is presented in **Figure 7** and it can be explained by the fact that many exits are available to get out of the building.

We have also noticed that the alarm has a big influence on the outcome of the evacuation, since the percentage of survivors increases considerably when there's an alarm in building. This is in conformity with our expectations.

Regarding the number of evacuee agents, our results show that the percentage of survivors slightly decreases when there are more agents trying to escape, although not as much as expected. This result can be explained by the fact that even though the communication between the agents was enabled during the simulation, when the number of evacuees increases past a certain point, there is a bottleneck regarding the lack of space.

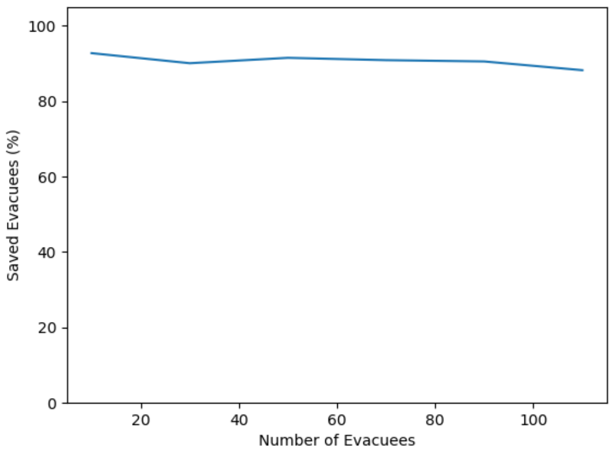

Figure 9: Influence of the number of evacuees on the percentage of saved evacuees.

4 CONCLUSION

We must take into account the fact that the percentage of saved evacuees strongly depend on the chosen values for the control parameters that did not change across the simulation due to not being the main focus of evaluation here, such as the fire and smoke damage and propagation rate. The chosen values for this parameters, which we figured that were the ones that resembled the real world the most, lead to a small discrepancy in the percentage of saved evacuees but when talking about human lives, every variation matters. Finally, we can say that with our framework it is possible to use different building layouts in order to study what are the better layouts for emergency evacuations, despite this not being the goal of our work.

5 FUTURE WORK

We presented a multi-agent system approach to evaluate the impact of human behaviors such as the willingness to take risks and the willingness to communicate during emergency evacuations. For future work, other ways of modelling risk-prone and risk-averse agents would be interesting, while also incorporating evacuees with different ages leading to different speeds and health levels. Modelling evacuations in buildings with various floors would also be interesting.

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