Modeling a Real-Case Situation of Egress Using BDI Agents with Emotions and Social Skills

Marion Valette, Benoit Gaudou, Dominique Longin, Patrick Taillandier

Modeling a Real-Case Situation of Egress Using BDI Agents with Emotions and Social Skills: 21st International Conference, Tokyo, Japan, October 29-November 2, 2018, Proceedings

Chapter · October 2018

DOI: 10.1007/978-3-030-03098-8_1

Benoit Gaudou
Toulouse 1 Capitole University

Dominique Longin
Institut de Recherche en Informatique de Toulouse

Patrick Taillandier
French National Institute for Agricultural Research

Modeling a real-case situation of egress using BDI agents with emotions and social skills

Marion Valette[1,3], Benoit Gaudou[2,4], Dominique Longin[1], Patrick Taillandier[3]

[1] CNRS-IRIT, Paul Sabatier University, Toulouse, France
[2] University Toulouse 1 Capitole, UMR 5505 IRIT, CNRS, Toulouse, France
[3] MIAT, INRA, Toulouse, France
[4] Sorbonne University, IRD, UMMISCO, F-93143, Bondy, France
Contact author: benoit.gaudou@ut-capitole.fr

Abstract. To be realistic, evacuation simulations have to consider several aspects of the human psychology that affect their decision-making process. Among them we find social relationships and emotions like fear. The former has been proven to have a great influence on the outcomes of simulations as they modify the behaviour of agents to make them escape in groups. This phenomenon strongly affects the efficiency of the evacuation. The latter impacts the ways the people will try to escape, leading to adaptation and unplanned behaviour. This paper presents an evacuation model that includes cognition with a BDI architecture to represent the way agents do complex reasoning, social relationships and a modelling of fear. The model is applied to simulate the fire of the Rhode Island Station Nightclub in 2003. We shows that after calibration, the model enables to reproduce in a credible way the real event.

Keywords: BDI · Egress · Simulation · Social relationships · Emotions.

1 Introduction

In the domain of evacuation studies, it is almost impossible to make real-scale experiments. Indeed, the behaviour of the people involved in fire drills is different from the one they would have in real egress, as their physical integrity is not actually threatened. Besides, it is forbidden by ethics to perform experiments with humans without telling them what they participate in. This is why simulations are needed to help design better security policies. But in order to be used as scientific or decision-support tools, simulations involving humans have to be realist in terms of human evacuation behaviors and therefore consider and implement many aspects of their cognition, and in particular the factors that influence their decision-making process in emergency situation.

This article introduces a model including cognition with a BDI architecture, social relationships and emotions and studies the relationships and interactions between them. This model, that is highly modular, enables to separately and simultaneously use these different aspects in order to control the complexity of the model. It uses the BDI (for Belief, Desire, Intention) [10,15] paradigm to model the cognition of agents and takes into account the social relationships between people and their emotions, particularly fear. The first level of social relationship taken into account by an agent is the group of close relationships: friends will first try to gather before evacuating together (one of the individuals becoming the leader and the other ones following him/her). The second level is related to gregarious and imitation behavior: in some specific situations, individuals can follow a crowd of unrelated people. In addition, the model allows the agents to adapt to the situation, for example by exiting in some extreme situations through windows instead of using the doors initially recognized as exits.

The model was implemented with the GAMA platform [12]. This open-source platform, which is dedicated to the development of simulation of agent-based models, allows to easily integrate spatial data such as building plans. In addition, it provides modelers with numerous primitive dedicated to agent movement, which greatly eases the development of pedestrian models. At last, it integrates a BDI architecture that includes several modules dedicated to social relationships, emotions and norms [6].

In order to illustrate how the model enables to reproduce in a credible way egress situation, we propose in this paper an application for the classic case-study of the evacuation of the Station Night club.

The paper is structured as follows. In Section 2, we further discuss the importance of the three aspects cited above. Section 3 describes the case study that is used to illustrate the model. In Section 4, we depict the model using the ODD protocol. Afterwards, in Section 5, the results of the simulation for the case study are presented. In Section 6, some scenarios are tested to show the influence of a few parameters.

2 State of the art

Multiple simulations of emergency situations already exist. But places like office buildings and railway stations, whose evacuation has been largely studied, are mostly occupied by business people, who are familiar with the environment and disconnected from one another [24,18]. Some models only consider crowds without making any distinctions between agents, using for example model based on forces [20] or cellular automaton [4].

Buildings like airports [22] or nightclub in contrast bring together people who have no or little knowledge of their surroundings, and often who have strong social relationships. Therefore simulations of such places need to consider more aspects than just the individual movement of each person. Many models [9,11] have shown the importance of taking into account the social relationships that exist in groups, in particular in egress situations, as they have a great influence on the death toll and duration of the evacuation. People indeed tend to escape in groups, so they must look for their friends and relatives before reaching an exit, which considerably increases the evacuation time.

In addition, as it is recognized to be a key factor in egress situation, some focus on complex representations of emotions, for example based on the Orthony, Clore and Collins' theory [17,2,16]. But few models include all three aspects (differentiation of persons, social relationships and emotions) and thus the way they interact to drive the agent behavior.

Finally, to obtain realistic simulations, the complexity of human behaviour needs to be captured. Therefore cognition has to be implemented. For this purpose, different architectures such as the ones listed in [5] have been theorized and developed. The BDI architecture [7] has proven itself to be well adapted to model humans [1,3], as it is close to folk psychology and natural language. Several works such as [19] have already used this architecture to model the crowds during emergency evacuation, but without considering all the aspect mentioned above.

3 Case-study: the Station Night club evacuation

The case-study we propose to use as a base to present our model concerns the fire of the Station Night club, located in Rhode Island (U.S.A), which burned on February 20, 2003 (see Fig. 1). This case study is that it has been studied extensively in the past and there is a lot of information on it allowing to validate the model proposed. The fire was triggered by the ignition of polyurethane foam on the walls and ceiling by pyrotechnics. The ignition points were located on the raised platform on the east side of the building (see Fig. 1). It spread rapidly, whereas a dense black toxic smoke filled the whole club. In less than 3 minutes, the flames were all over the place. The building was mainly made of wood and had no sprinklers. That night, the building hosted about 465 persons, more than the authorized limit, which led, despite a rapid intervention of the firemen, to a heavy human toll, with 100 deceased persons and 230 injured. People started to evacuate approximately 20 seconds after ignition, and most persons escaped during the first 150 seconds. There were four exits: the front door entrance or main entrance, the main bar exit, the kitchen exit, and the platform exit.

The platform exit was blocked by the staff who reserved it for the musicians and professionals. Besides, it became fast unreachable because of the spreading of the fire, which explains the low number of people who escaped through it. The kitchen door was also badly indicated and visible. The two remaining exits were fast blocked by the crowd, so some people started to look for alternatives, and broke the windows situated on the northern wall. About one third of the evacuees used that way to escape, one third went through the main entrance, and the last third split into the three other doors. The actual figures are summarized in Table 1. All real data come from El-Tawil *et al.* [11].

Table 1. Distribution of the people having evacuated through each exits

Main	Bar	Kitchen	Platform	Windows
128	78	17	24	105

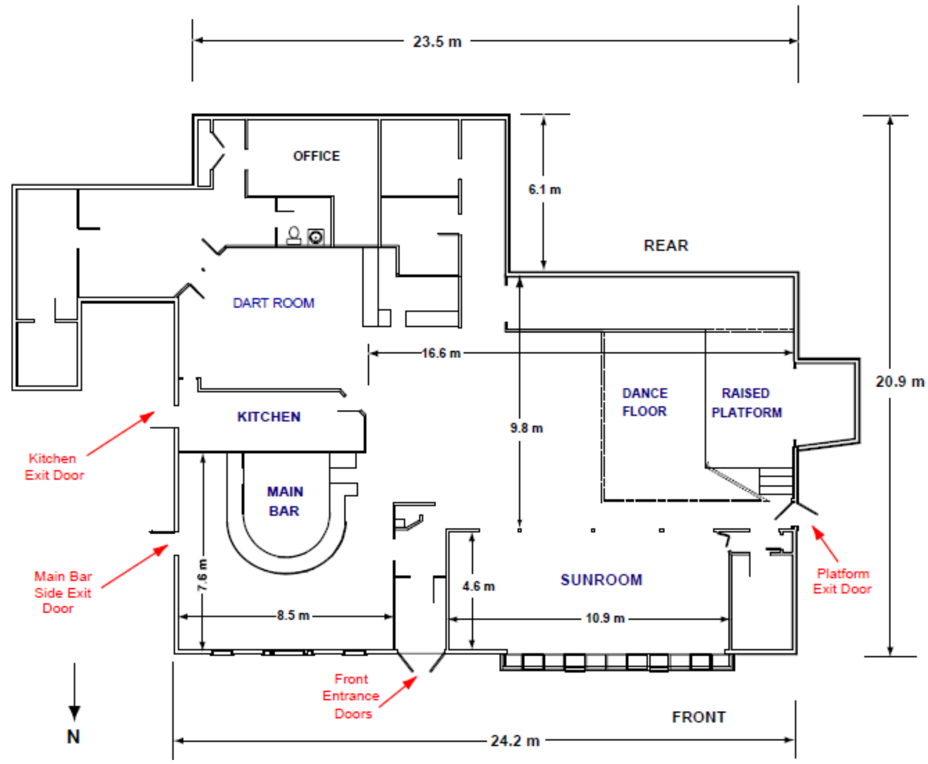

Fig. 1. Plan of the night club with indication of the exits (Copied from [14])

4 Description of the model

In the following, we describe the model using the ODD (Overview, Design concepts, and Details) protocol [13]. This is a standard protocol designed to describe individual-based and agent-based models, in order to make them more understandable.

4.1 Purpose of the model

The purpose of this model is to simulate the evacuation of a building, in particular night-clubs, in order to evaluate the influence of emotions and social relationships [8,6] on the efficiency of the evacuation.

4.2 Entities, state variables and scales

This model includes several types of entities. Their most important variables and actions are presented in the class diagram shown in Fig. 2.

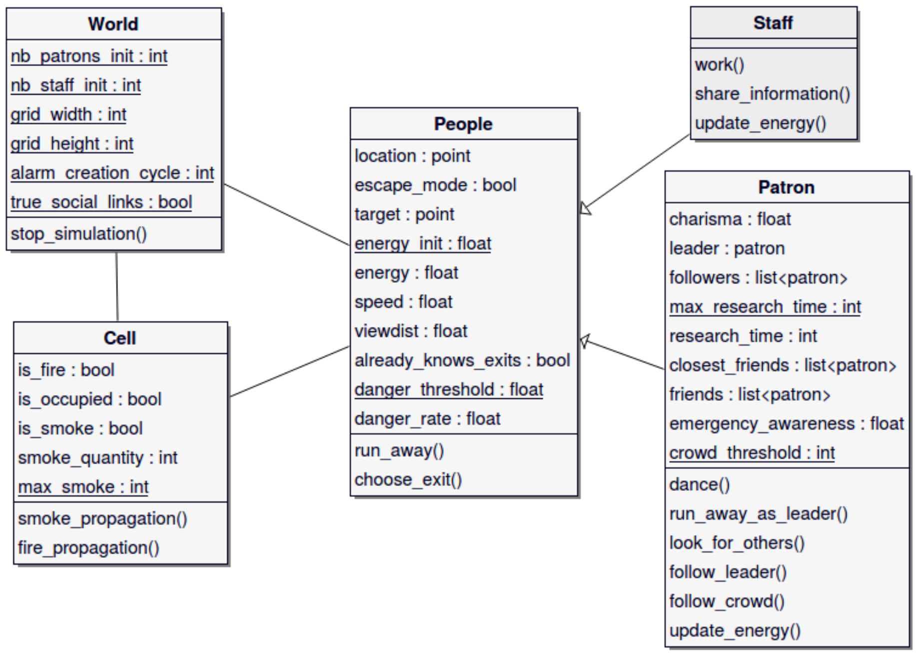

Fig. 2. Class diagram of the model

The key entities represent people agents. The People species contains all the attributes (target destination, speed, a set of known exits) and action (choose an exit and run away) related to the individual evacuation. It also includes the management of people emotions with *danger_rate*, which represents the fear emotion intensity, and *danger_threshold* attributes. The People species is specialized in two sub-types of agent: Staff and Patron.

Staff main objective is to help Patrons to evacuate the building by sharing information about exits. Patron agents add mainly the social components to the People agents: it adds the lists of close friends and of possible followers, a charisma value, used to determine the leader in a group of close friends, the maximum search time before leaving the place without the missing friends, a crowd threshold, used to determine when a patron stops to follow its leader to follow the patrons around him, and an emergency awareness, which characterizes the response time of an agent when it perceives the danger. In the following, unless specified, the term group refers to friends spatially close, when the expression friend group or social group refer to the whole social group of the agents, which can be physically divided. As far as actions are concerned, it introduces the capability to look for others or follow leaders.

Finally the building is discretized using a grid of Cells. These Cell agents are used to diffuse the fire and smoke. They are also used to help the computation of the shortest path to the exit chosen by each agent who is running away from the fire.

One time step represents one second, and the simulation lasts until there is no more living people inside the building.

4.3 Process overview and scheduling

As it is classical in agent-based models, the simulation is based on discrete time steps. As far as agent activation order is concerned, we rely on the default scheduling on the model underlying GAMA.

Actions during an simulation step are executed in the following order (each one is detailed in Section 4.7):

- the patrons are activated in their order of creation (patron 0 first, then patron 1, *etc.*). They start by the perceptions of their environment. This includes a phase of determination of the leader of each group. Then, they move according to their goals, which depend on their social relationships with the other people in the building and on personal characteristics. Their fear is modeled by a numerical value (danger rate) and a threshold, above which the behaviour of the agent is modified (valid also for the staff);
- the staff is activated, they perceive their environment. Then they help the patrons near them. If there is nobody or if their danger rate is too high, they run away;
- Every two time steps, the grid propagates the fire to the four neighbors of each cell in fire and at every iteration, it propagates the smoke to the eight neighbors of cells whose smoke density is greater than a given threshold. Here the cells are activated in a random order.

4.4 Design concepts

Basic principles. This model uses the BDI paradigm [10,15] to implement cognitive agents [23]. It relies on the BDI architecture implemented in GAMA, described in details in [8,21]. It is based on three sets: the belief base (what the agent believes to be true), the desire base (what it wants), and the intention base (what it is doing).

In our model, the beliefs are only used to model the knowledge about the exits. Each agent has the beliefs of the location of each exit it knows. The BDI architecture provides primitives to automatically create beliefs or desires from perceptions. When an agent perceives an exit by walking near it, this one is added to its belief base.

The desires of an agent depend on its species (patron or staff), its social relationships, or if it is a leader or not, *etc.* Each desire has a priority. The choice of an intention to fulfill among the existing desires is driven by theses priorities: when the agent has no intention, the desire with the highest priority becomes the intention. The agent will then execute the plan corresponding to its intention. If a new desire with higher priority arises, it can drop its intention to consider a new one.

To fulfill its intentions, the agent has a set of plans that will be executed if the activation condition (expressed in terms of intention) is fulfilled. In our model, the people agents have two plan: running away and choosing an exit. Patron agents have three additional plans: looking for their friends, following the leader, and following the crowd. At last staff agents have all the people agent plans and the plan to share information. All the plans are described in Section 4.7).

This architecture has the advantage to help the design of modular agents internal structure, separating clearly the perception and the actions, executed in plans. These two components are coupled through the various mental states of the agent.

Adaptation. The patrons have a danger rate, which allows them to change their behaviors when the close environment is changing. For example, when their danger rate becomes too high, they can change their target, and if it was an exit, it is no longer considered as a possible way out. They can also decide to break a window to go out quicker. This is a way to get out that was not planned at the origin for them.

Sensing. All agents have a view distance, within which they can perceive several things like the fire and the exits. Furthermore, each species of agents has specific perceptions. The staff can perceive the patrons to inform them of the exits. The patrons can perceive their friends and the patrons who are heading to a window. This perception can be interpreted as a capacity to imitate the behaviour of others. After this perception, the agent can indeed change its target to go to the window too. Moreover, the agents can hear the alarm.

Interaction. Two agents cannot be on the same cell, thus the movement of an agent will be impacted by the other agents. In addition, the patrons in a group interact via a leader / follower relationship, that is, a patron follows its leader but have no interaction with the other members of its group. Furthermore, the staff shares information about the exits with the patrons, to do so they give them the location of the exits. They also interact in order to tell others that they have to flee if they are not already aware of that.

Stochasticity. During the initialization, people are placed randomly in the available space. Their initial value of speed is randomly chosen between two realistic bounds, when their initial value of energy, their emergency awareness and their charisma are chosen between two arbitrary limits. Their danger threshold, maximum search time and crowd threshold are chosen in a range of values defined around the related global parameter[5].

[5] These parameter values are computed in the calibration presented in Section 5.

During the simulation, the targets of patrons who are looking for their friends are random. In the case where the agent who wants to run away is stuck or in too much danger, the exit it will go to is randomly chosen among its known exits.

The cells of the grid are activated in a random order to simulate a more realistic propagation of the smoke and fire.

Observation. The model is observed through a 3D representation (see Fig. 3) of the building with visuals of the patrons, staff, fire, smoke. It is also possible to at every time step different information about the agents like their danger rate, *etc.*. There are also monitors which shows the number of dead, injured and safe

Fig. 3. 3D visualization of the simulation

and sound people, and the number of people who went out through each door.

4.5 Initialization

At the beginning of the simulation, all agents and variables are created and initialized. First the geometries (walls, bars, and exits) are built from shape file input data, then the grid is created. The initial number of patrons is created, the socials links are determined, based on real data [11], with the following rules: one agent can be a member of only one group of friends, and these friends are randomly selected among a list. This list is composed of all the persons close to the agent and of a few persons spatially further. At last, the staff is created, with one person located near the exit next to the raised platform (where the fire starts) to prevent patrons from using this door. At that moment, each patron is its own leader.

The clients are in majority placed randomly in the dance floor, while the rest and the staff are randomly placed in the building. The staff knows all exits, while only a third of the patrons have already been there before and know three exits (the main one, the one near the main bar and the one near the the raised platform). All other patrons only know the main entrance.

4.6 Input data

The model uses *shape files*[6] to design the walls, bars, and exits. The model users have also to provide information about the human agents, such as their number and the distribution of the size of the social groups.

4.7 Sub-models

Smoke and fire spread As the main goal of the model is to evaluate the impact of social behaviors on evacuation, we chose for this first version of the model to use simple smoke and fire diffusion models, but we plan to integrate more realistic models in the further.

Thus, in our model, every two time steps, each cell in fire propagates it to its four closest neighbours. The cells are activated in a random order to ensure a little bit of realism in the propagation. The Fig. 4 explains the beginning of this process. The number in each cell refers to the activation order, the cells in red are in fire.

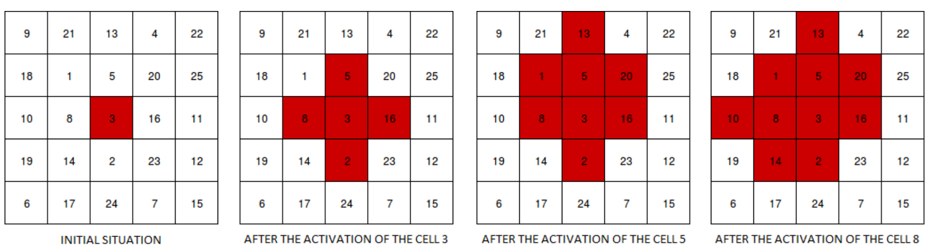

Fig. 4. Propagation of the fire

With regard to the smoke, the propagation principle is slightly different. Each cell has a smoke density, that can vary between 0 and a maximum quantity (here 100). At the beginning of the fire, we set the smoke density of the cells in fire and their neighbours to the maximum. To be able to propagate the fire, a cell has to have a density strictly greater than 1. Then the smoke propagates with the same pattern as the fire, except for the fact that it spreads to the eight neighbours. Each time the smoke propagates to a cell, its smoke density is increased by one.

[6] A shape file is a file format for geographical information systems, it contains all the information linked to the geometry of the described objects.

Search. As soon as a patrons detects the danger, by perceiving the fire or the alarm, it starts to look for its group of friends. Since all patrons are their own leader at the beginning of the simulations, they all do the following: as long as the group is not complete or the maximum search time has not been reached, the leader looks for its friends. They remember where they have seen their friends for the last time, so their first targets are those locations. If during their moves, friends find each other, a leader is determined from their charisma, except in the case where a friend alone finds a group already formed, here the leader of the group stays leader (cf. Fig. 5).

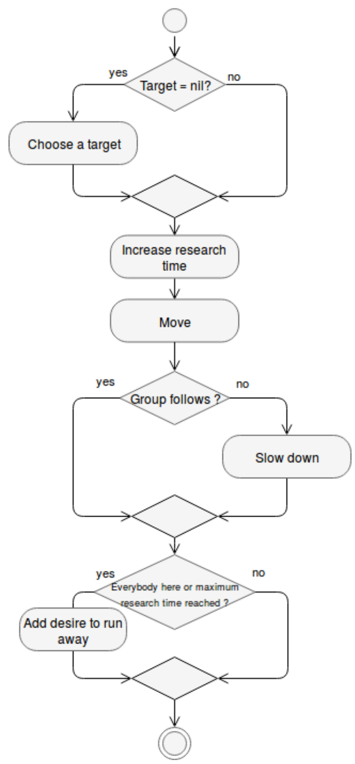

Fig. 5. Looking for others

Evacuation.

Run away. Leaders and persons alone who want to run away first choose a target. To this end, if they are not in danger, they choose the closest exit among their known doors. Otherwise they choose a random one. They can choose a new target if the danger becomes too important. If their danger rate is higher than their respective thresholds or if at least one of the windows is broken, they can choose to exit through the window. Then they move towards that target, and when they reach it, they are removed from the simulation.

Follow leader. The others patrons follow their leader when it looks for others or toward an exit. Therefore, they move on a cell near the one of the leader. If their leader dies, they have the desire to keep looking for other friends.

Follow the crowd. When a follower is too far from its leader, and surrounded by more people than its crowd threshold patrons, it begins to follow them. That means that its heading is the mean of the heading of the costumers around him. If the number of patrons near him becomes less than the half of the threshold, the agent changes its intention to look for others.

Updates of attributes.

Speed. The speed is updated according to the level of energy of the agent through the following formula:

$$speed = \begin{cases} speed\_init & \text{if } energy > 0.8 * energy\_init \\ speed\_init * \frac{energy}{0.8 * energy\_init} & \text{else} \end{cases}$$

In addition, for the leader, it also depends on whether the others are following it or not. If the group that follows the leader is not physically close enough to it, the speed of the leader will correspond to the minimum between the value computed from the previous formula and the min of the follower speeds divided by two.

Danger rate. The danger rate is computed from the mean of smoke density (normalized by the maximum quantity) in the cells visible for the agent (VC) with the following formula:

$$danger\_rate = \frac{energy\_init}{energy} * \frac{\sum_{c \in VC} \frac{smoke\_quantity_c}{max\_smoke}}{\#(VC)}$$

where $smoke\_quantity_c$ is the smoke quantity of the visible cell c. Thus, it increases when the agent looses energy and is surrounded by a high quantity of smoke.

Energy. Each agent who is located on a cell on fire looses 2 points of energy. If it is on a cell c with smoke, it looses $1.5 * \frac{smoke\_quantity_c}{max\_smoke}$ points of energy. These numerical values are a simplification of the rules described in [11].

Share information. The staff can inform the clients near them about all the exits of the building. Moreover, if the patron knows the exit near the stage, they forbid him to use it, as it is considered to be reserved for the musicians and staff.

5 Results

The model was applied to the case study of the Rhode Island Station Nightclub. For that, we digitized the nightclub plan as shapefiles. We used the data provided by [11] to initialize the human agents and the real values for the time of the alarm triggering (30s) and the initial number of staff members (10) parameters.

To make the model closer to the reality, we calibrated it using a genetic algorithm. Three parameters were concerned by this calibration: the fear threshold, the crowd threshold (the limit of people around a follower which makes him start to follow the crowd instead of its leader) and the maximum search time (in seconds). These parameters are used to initialize the related attributes for each agent: the value of their attribute corresponds to a random value choice around the parameter value. We run 4 replications for each parameter value set. The final parameter set is given in Table 2. The fitness function used for the calibration was computed from following indicators: the numbers of deceased people, of injured people, of safe and sound people, and the numbers of people who exited through each exit, including the windows.

Table 2. Parameters of the base case

	Danger threshold	Crowd threshold	Maximum search time
Minimum	0.3	15	10
Maximum	0.6	35	15

Table 3 shows the results obtained with this parameter sets. The results are close to the real ones. However, as shown by the high value of the standard deviation, the simulation results vary a lot from one to another.

Table 3. Comparison between reality and simulations (mean on 1120 runs)

		Deceased	Injured	Main exit	Windows
Reality		100	230	128	105
Simulation	Mean	121	202	161	112
	Std	22	17	49	51

6 Scenario

We first tested two scenarios to show the influence of the emotions and of social relationships, before testing the impact of the number of staff members and of the environment awareness.

6.1 Scenario 1: Influence of emotions

As a first experiment, named Scenario 1, we remove the fear from the simulation. We observe more deceased people, which can be explained by the fact that they tend, without the effect of the fear, to stay longer in the toxic smoke. Furthermore, as the decision to escape through a window is triggered by fear, the number of people exiting this way falls to zero. More people used the main entrance and the others values do not significantly change (see Table 4 where the results of the Scenario 1 are compared to the Base Case, corresponding to the results after the calibration).

Table 4. Comparison between the calibrated results (Base Case) and the results of the Scenario 1, where emotions do not have any effect on the behaviour (in number of people, mean over 764 runs for the tested case)

	deceased	safe	injured	main exit	windows
Base case	121	132	202	161	112
Scenario 1	158	133	164	230	0

6.2 Scenario 2: influence of social relationships

In a second experiment, called scenario 2, we tested the influence of social relationships by removing them. We obtain the results summed up in Table 5. The result shows that the number of casualties has drastically diminished, since the patrons go right away to the exits. They tend to exit more by the main entrance and the windows as they are the closest from the dance floor.

Table 5. Comparison between the calibrated results (Base Case) and the results of the Scenario 2, where Patrons do not have any social relationships (in number of people, mean over 596 runs for the tested case)

	deceased	safe	injured	main exit	windows
Base Case	121	132	202	161	112
Scenario 2	28	234	193	208	181

6.3 Scenario 3: adding staff

We progressively increase the staff member number to see if they can help to decrease the casualties by giving information about unsaturated exits. Therefore we run the simulations with respectively 10 (normal case), 30 and 50 staff members. As this makes the total number of persons in the club vary, the results are the proportion (in percentage) of persons deceased, injured, safe and sound and through each exit. Table 6 shows that the proportions of people who escape safely increases as the proportion of injured people decreases. But as the standard deviations for those results are respectively around 25 (deceased), 18 (safe) and 18 (injured), the observed variations are too small to be significant. Fewer people leave through the main exit and more through the kitchen and bar ones, as more people know them thanks to the staff. Consequently, the proportion of people who go out through the windows decreases.

Table 6. Proportions' evolution with the number of staff members (in percentage)

staff members	deceased	safe	injured	bar exit	main exit	windows
10	26.6	29.0	44.4	8.7	35.5	24.7
30	27.0	30.1	42.9	10.8	33.5	23.4
50	27.1	31.1	41.8	12.5	32.9	22.0

6.4 Scenario 4: more environment awareness

We carried out a last experiment to evaluate the sensibility of the simulation results to the variation of the awareness parameter around the solution found though calibration. This corresponds to evaluate the impact of providing more information to the patrons about the club. We ran simulations with respectively 33% of people who knows several exits (normal case, obtained after calibration), 66% and 100%. Table 7 shows that the number (or proportion as the initial number of persons inside is constant) of injured costumers remains constant, whereas the number of deceased people increases slightly. The numbers of people exiting through the kitchen's and scene's exits raise and the one through the bar's and main exit fall. Regarding the windows, the numbers are roughly constant.

Table 7. Proportions' evolution with environment awareness (in percentage)

awareness	deceased	injured	bar exit	kitchen exit	main exit	windows
33%	26.6	44.4	8.7	4.2	35.5	24.7
66%	27.6	44.6	6.2	6.2	34.8	24.6
100%	28.6	44.7	3.6	8.2	33.4	25.6

As the variations are really small, we can conclude that the awareness does not have influence on the simulation, around the solution found by the calibration.

7 Conclusion

In this paper, we described an evacuation model which includes three main features: a BDI architecture, social relationships and emotions, implemented with the GAMA agent-based modeling and simulation platform. The model has been apply to reproduce the event that occurred at the Station Nightclub. After calibration, the model has allowed to reflect the reality of the case study, which allowed us to test different scenarios. These experiments showed the importance of taking into account the emotions and social relationships in that type of model as they profoundly influence the outcomes of the simulation.

With this model, we are facing a classical issue when we want to reproduce some extreme event: we only have a single data set to calibrate on, which can restrict the generic aspect of the model and produce simulation results with a large variability. Future search will thus invest new methods of calibration dedicated to this issue.

To improve the credibility of the model, we plan as well to integrate in the further more realist models of fire and smoke propagation. To this purpose, we are currently working on a module dedicated to the importation of 3D BIM (Building Information Modeling) data-models. These data-models are nowadays a standard for describing buildings in civil engineering and architecture, and will allow us to directly reuse realist fire and smoke propagation models.

Acknowledgment

This work is supported by the ANR ACTEUR project.

References

1. Carole Adam and Benoit Gaudou. BDI agents in social simulations: a survey. *The Knowledge Engineering Review*, 31(3):207–238, 2016.
2. Carole Adam, Andreas Herzig, and Dominique Longin. A logical formalization of the OCC theory of emotions. *Synthese*, 168(2):201–248, 2009.
3. Carole Adam, Patrick Taillandier, and Julie Dugdale. Comparing agent architectures in social simulation: BDI agents versus finite-state machines. In *HICSS*, 2017.
4. R. Alizadeh. A dynamic cellular automaton model for evacuation process with obstacles. *Safety Science*, 49(2):315 – 323, 2011.
5. Tina Balke and Nigel Gilbert. How do agents make decisions? a survey. *Journal of Artificial Societies and Social Simulation*, 17(4):13, 2014.
6. Mathieu Bourgais, Patrick Taillandier, and Laurent Vercouter. Enhancing the behavior of agents in social simulations with emotions and social relations. In *MABS2017*, pages 89–104. Springer, 2017.
7. Michael Bratman. *Intention, Plans, and Practical Reason.* Center for the Study of Language and Information, 1987.
8. Philippe Caillou, Benoit Gaudou, Arnaud Grignard, Chi Quang Truong, and Patrick Taillandier. A simple-to-use BDI architecture for agent-based modeling and simulation. In Wander Jager, Rineke Verbrugge, Andreas Flache, Gert de Roo, Lex Hoogduin, and Charlotte Hemelrijk, editors, *Advances in Social Simulation 2015*, pages 15–28, Cham, 2017. Springer International Publishing.

9. Mei Ling Chu, Paolo Parigi, Kincho H Law, and Jean-Claude Latombe. Simulating individual, group, and crowd behaviors in building egress. *Simulation*, 91(9):825–845, 2015.
10. Philip R. Cohen and Hector J. Levesque. Intention is choice with commitment. *Artificial Intelligence Journal*, 42(2–3):213–261, 1990.
11. Sherif El-Tawil, Jieshi Fang, Benigno Aguirre, and Eric Best. A computational study of the station nightclub fire accounting for social relationships. *JASSS*, 20(4):10, 2017.
12. Arnaud Grignard, Patrick Taillandier, Benoit Gaudou, Duc An Vo, Nghi Quang Huynh, and Alexis Drogoul. Gama 1.6: Advancing the art of complex agent-based modeling and simulation. In G. Boella, E. Elkind, B. Savarimuthu, F. Dignum, and M. K. Purvis, editors, *PRIMA 2013*, pages 117–131. Springer, 2013.
13. Volker Grimm, Uta Berger, Donald L. DeAngelis, J. Gary Polhill, Jarl Giske, and Steven F. Railsback. The ODD protocol: A review and first update. *Ecological Modelling*, 221(23):2760 – 2768, 2010.
14. William Lytle Grosshandler, Nelson Bryner, Daniel Madrzykowski, and Kenneth Kuntz. Report of the technical investigation of the station nightclub fire. Technical Report 2, National Construction Safety Team Act Reports (NIST NCSTAR), 2005.
15. Andreas Herzig and Dominique Longin. C&L intention revisited. In Didier Dubois, Chris Welty, and Mary-Anne Williams, editors, *KR 2004, Whistler, Canada, June 2–5*, pages 527–535. AAAI Press, 2004.
16. E. Lorini, D. Longin, and E. Mayor. A logical analysis of responsibility attribution: emotions, individuals and collectives. *Journal of Logic and Computation*, 24(6):1313–1339, 2014.
17. Andrew Ortony, Gerald L Clore, and Allan Collins. *The cognitive structure of emotions*. Cambridge university press, 1990.
18. Tzu-Sheng Shen. ESM: a building evacuation simulation model. *Building and Environment*, 40(5):671 – 680, 2005.
19. Ameya Shendarkar, Karthik Vasudevan, Seungho Lee, and Young-Jun Son. Crowd simulation for emergency response using bdi agents based on immersive virtual reality. *Simulation Modelling Practice and Theory*, 16(9):1415 – 1429, 2008.
20. Weiguo Song, Xuan Xu, Bing-Hong Wang, and Shunjiang Ni. Simulation of evacuation processes using a multi-grid model for pedestrian dynamics. *Physica A: Statistical Mechanics and its Applications*, 363(2):492 – 500, 2006.
21. Patrick Taillandier, Mathieu Bourgais, Philippe Caillou, Carole Adam, and Benoit Gaudou. A BDI agent architecture for the GAMA modeling and simulation platform. In Luis Gustavo Nardin and Luis Antunes, editors, *MABS*, pages 3–23. Springer International Publishing, 2017.
22. Jason Tsai, Natalie Fridman, Emma Bowring, Matthew Brown, Shira Epstein, Gal Kaminka, Stacy Marsella, Andrew Ogden, Inbal Rika, Ankur Sheel, Matthew E. Taylor, Xuezhi Wang, Avishay Zilka, and Milind Tambe. ESCAPES: Evacuation simulation with children, authorities, parents, emotions, and social comparison. In *AAMAS*, pages 457–464, Richland, SC, 2011.
23. Michael Wooldridge. *Reasoning about Rational Agents*. MIT Press, 2000.
24. J.P. Yuan, Z. Fang, Y.C. Wang, S.M. Lo, and P. Wang. Integrated network approach of evacuation simulation for large complex buildings. *Fire Safety Journal*, 44(2):266 – 275, 2009.