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MODELING AIRPORT EVACUATION UNDER EMERGENCY USING AGENT-BASED MODELS

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Abstract. *This paper presents an agent-based evacuation simulation framework in an airport setting. Air transport services have become a nerve system of our society, therefore, aircrafts and airports represent a central component of todays traffic system. A significant heterogeneity of processes and a high levels of surveillance define the uniqueness of this scenario. Building Evacuation is an important application field for the Agent-Based Modeling (ABM). In recent years, there has been an increasing amount of literature on airport analysis and modeling, but not so many have simulated emergency evacuation using agent-based modeling. In this research three hazardous scenario are modeled: (i) an earthquake, (ii) an accident (fire) and (iii) a terrorist attack (shooting). In all three cases the model takes into account the main actions that an agent can perform during the evacuation: the search of the optimal escape route, the leader-follower behavior and the research of a missing person. Three types of agents are modeled in the simulation: the aircraft passengers, the security agents (or aircraft crew) and the robbers. The first type has an incomplete knowledge of the area, unlike the security agents who can reach the emergency exit walking the shortest path, then their first task is to help the other agents to reach the closest exit. A cross platform Java-based modeling system called Repast Simphony has been used to develop the ABM. This tool provides decision support in a real emergency scenario in order to study the dynamics of evacuation, helping to improve the infrastructure reliability and its response when a critical situation occurs and also assessing the effect of a certain number of security agents in the area. In order to show the implementation issue the framework has been used to model the Fiumicino Leonardo da Vinci International Airport in Rome and the two decks of an Airbus A380-800, however it can be easily extended to other types of environments.*

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1 INTRODUCTION

Air transport services have become a nerve system of our society, therefore, aircrafts and airports represent a central component of todays traffic system. A significant heterogeneity of processes, high levels of surveillance, emotional component define the uniqueness of this scenario, passenger dynamics within it appear to be complex as well. Emergency evacuation is an important application field for the Agent-Based Modeling (ABM). In recent years, there has been an increasing amount of literature on airport and air transportation analysis and modeling, but not many have simulated the crisis management using agent-based modeling. Thousands of people, everyday, spend their time in airports and travel using airplanes, in crisis events a rapid but safe evacuation is critical. Conducting live exercises for evacuating so many people is impossible, therefore an appropriate simulation becomes essential.

Agent-Based model is a class of computational models for simulating the actions and interactions of autonomous agents (both individual or collective entities) with each other and the environment. ABM is class of micro-scale models, that simulate the simultaneous operations and interactions of multiple agents assessing their effects on the system as a whole, recreating and predicting the appearance of complex phenomena, as such the main consideration is that simple behavioral rules generate complex behaviors. This approach, then, appears to be particularly suitable in order to model complex and heterogeneous systems as pedestrian evacuation after extreme events. By running thousands of simulations under different parameter assumptions, researchers can evaluate several scenarios in order to get awareness and insight into potentially rescue management policies and also assessing on the infrastructure design.

The aim of this research is to develop an agent-based evacuation simulation framework in order to provide a decision support in a real emergency scenario in order to study the dynamics of evacuations, helping to improve the infrastructure reliability and its response when a critical situation occurs and also assessing the effect of human behavior during the evacuation. The ability to quickly unload passengers from an aircraft or to evacuate a public building, like an airport, as fast as possible or are not only important in order to optimize the daily operations, but also vital requirements to manage an emergency event. The model is also intended to guide the designers to estimate the aircraft or airport safety, considering this issue in the course of the interior designing. Nature of customers population, the personnel procedures and their typical behaviors are some of the essential elements to consider during this stage. By simulating different occupants behaviors, in several scenarios, engineers and facility managers may better understand the influence of human and social factors on evacuation and consequently design safer infrastructures and egress procedures.

In this research three hazardous scenario are modeled: an earthquake, a shooting, and an accidental fire. In all three cases the model takes into account the most important actions that an agent can perform during the evacuation: the seeking of the best escape route, avoiding the imminent hazard, the leader-follower behavior, the research of a missing person. The agents, hence, are able to perform decisions, but they can also have some irrational behaviors, simulating the panic condition. The main agent types are the aircraft passengers and the security agents (or aircraft crew). The first type has an incomplete knowledge of the area, then they explore the environment in order to find the emergency exit. The security agents, instead, can reach the emergency exit walking the shortest path, then their first task is to help the other agents to escape, reaching the best exit. The model implements both the crowd and the individual behavior. The pedestrian behavior is simulated thanks to the A^* algorithm, opportunely modified in order to better fit the research's requirements. The individual behavior module is developed using the

BDI technique. The passengers are differentiated in groups and alone agents, both the types can be injured or not injured, depending on this differentiation each agent behaves in such a specific way, choosing the next move with different probabilities.

Repast Simphony, a cross platform Java-based modeling system, has been used to develop the ABM. The framework was used to model the two decks of an Airbus A380-800 and airport's terminals, drawing inspiration from the Fiumicino Leonardo da Vinci International Airport in Rome. Moreover, thanks to the way it was designed the model can be easily adapted to any other scenario, therefore this model can be used to test future scenarios, helping designers and authorities to manage emergency situations.

2 STATE OF THE ART IN AGENT-BASED MODELS

Agent-Based model is a class of computational models for simulating the actions and interactions of autonomous agents (both individual or collective entities) with each other and the environment. ABM has been used in an wide range of applications spanning the physical, biological, social and management sciences.

ABM is class of micro-scale models, that simulate the simultaneous operations and interactions of multiple agents assessing their effects on the system as a whole, recreating and predicting the appearance of complex phenomena, as such the paramount consideration is that simple behavioral rules generate complex behavior. The agent-based modeling hence represent a bottom up approach, very useful in order to create artificial societies and very powerful to capture more complex structures and dynamics, moreover computational power is advancing and can now support micro-simulations. For these reasons this technique has seen an increasing number of applications in the last years.
Therefore, ABMs is the formalization of methods used to drive the production of microscopic models and observe their output for research purposes. A typical ABMs is characterized by a set of agents with their attributes and behaviors, a set of agent relationships and methods of interaction and finally the environment, whom the agents can also interact with [1].

Agent-based simulations appear to be particularly suitable in many context of transport management and in presence of extraordinary events, such as airport passenger terminals, railway, public buildings, urban areas. ABM are also very appropriate model complex and heterogeneous systems as pedestrian evacuation after extreme events.

Several works can be found in literature in recent years related to infrastructures evacuation models using ABM simulations, some of them, also focused their attention on airport and air transportation analysis.

Schultz at al. [2] developed an agent-based model for handling passengers in an Airport Terminal. The model is based on a stochastic approach for passenger movements including the capability of individual tactical decision making and route choice, and moreover, on a stochastic approach of the handling processes. Each component of the model was calibrated with a comprehensive, empirical data set. A virtual terminal environment was developed and real airport conditions were evaluated. The stochastic motion model defines the movement behavior of common agents and has to be adapted by specific parameters to determine passenger movements in the environment of an airport terminal. To validate the parameters of the passenger behavior model a test set-up in a real airport environment is needed, the recognition of movement behavior was handled by a video tracking software developed for this purpose.

Tsai at al. [3] developed ESCAPES, a multi-agent evacuation simulation system to model the International Terminal at Los Angeles International Airport (LAX). ESCAPES has different agents types such as children, authorities, parents based on the BDI framework, each type of agent has different characteristics and behaviors.

Individuals with disabilities are more likely to suffer during emergency situations, [4] created an agent-based model, EXITUS, that can be used to estimate the evacuation performance of heterogeneous populations from airports. The model classifies the environment according to accessibility characteristics (exit character, route character and obstacle), that have an effect on the behavior of individuals with disabilities during the evacuation. The simulation experiment estimates the impact of bomb placement on evacuation times for individuals with and without disabilities.

Most of the models treat pedestrians as individual agents and neglect the group dynamics among them, getting less realistic simulations results. Airport is a complex system with a huge number of social interactions, [5] in their simulation consider passengers as collective social groups. Pedestrians in the model are classified into: passengers, those who will complete all airport departure process and board on the plane and wavers, fellow companions, who accompany the passengers in the airport but do not board the flight. Agents are assembled into groups with predefined sizes while they are entering the simulation environment. The international airport departure terminal is divided into landside, open to the public and airside, only accessible for the passengers. When the evacuation event starts passengers will make their way to the nearest exit. The simulation results show that the evacuation time can be influenced by passenger group dynamics, suggesting that passengers with group dynamics spend longer time in making decisions, moving to the exits and waiting for other group members during the evacuation.

3 THE DEVELOPED MODEL

There are two fundamental approaches in literature in order to simulate infrastructures evacuation. The first scenario is when the agent knows the exact series of shortest paths to take to evacuate the building, the other scenario is when the agent does not know the shortest path, the evacuees are in an unknown environment, that they need to explore first.

This research aim to develop a new approach for evacuation models combining these two methods, in order to develop an as more comprehensive model as possible.

According with several researches and evacuation planning strategies, the target evacuation time t_m, being the time for clearing the occupants within the building, was specified to be 2.5 min [18]. Most of the research that rely, exclusively, on a shortest path algorithm to develop the pedestrian model within the agents-based simulation, use to determinate an underestimated evacuation time. Combining the environment exploration with the shortest path calculation, which presupposes a good knowledge about the infrastructure to evacuate, makes possible to achieve a simulation closer to reality.

The model takes into account the main actions that an evacuee uses to perform during an evacuation, under emergency: the search of the optimal escape route, the leader-follower behavior, the research of a missing person. As soon as the hazard occurs the passengers start looking for the closest emergency exit, since they are not aware about the precise door's dislocation they start exploring the environment, in order to find a security agent and the closest available exit, indeed some of them can be unusable with a probability to set at begging of the simulation.

The security agents (or aircraft crew), that can also be intended as rescue personnel, have a good awareness about the infrastructure map, then they can easily reach the exit walking the shortest path (determined using the A^* algorithm). Therefore, their first task is to explore the map looking for passengers to rescue, as soon as one of them is reached they can lead him to the safety. If a passengers meet more than two agents choose the one to follow relying on their charisma, which is a characteristic of each security agent, assigned stochastically. Only when each passenger has left the infrastructure (or is dead), the security is admitted to escape. As soon as in the simulation environment there are no more agents, the simulation is automatically stopped.

The model integrate a *crowd behavior module* in order take into account the main crowd behavior aspects: walls and obstacles avoidance, attraction from group of agents, the tendency to move toward the emergency exits and the queuing behavior, when the agents face an over-crowded door.

A *memory module*, was also developed. In the pursuit of their evacuation, passengers and the security agents are able to wisely explore the environment, the first in order to find an emergency exit and the last looking for passengers to rescue. Indeed, agents are able to remember the path they have already walked and then use to focus more the environment not visited yet. Modeling this behavior is dramatically important in order to make the agents behave reasonably and also for coherent time results.

Moreover, all the passengers are provided with an *individual behavior module*, in order to simulate human deliberation process in making decision under uncertainty and panic. In the course of their evacuation they can choose to move toward a group of people, reach an injured person needing help or simply keep going tho the emergency exit.

Three hazardous are modeled: (i) an earthquake, agents escape following the behavior described above; (ii) a fire, agents head to the exit trying to avoid the imminent hazard; (iii) a shooting scenario, the assailants aim to kill as more people as possible, in this case the security agents are able to return fire, trying to protect themselves and the passengers.

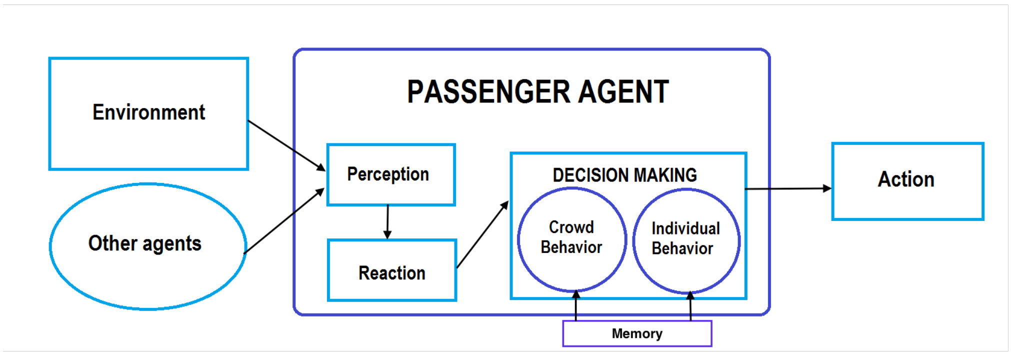


Figure 1: Structure of the passenger agent.

The authors provided the model with an its own, interactive, 2D graphical interface, a parameter panel is also available in order to easily modify the main model parameters (e.g. number of agents, their own characteristics, environment maps...) to run different simulations in order to investigate a wide range of scenarios.

3.1 The Repast Simphony platform

The evacuation model was entirely developed in Repast Simphony, a widely used free and open-source, cross-platform, agent-based modeling and simulation platform. Repast is fully object oriented and JAVA based, it includes many features such as: visual model development, point-and-click model configuration and operation, integrated 2D, 3D and GIS model views, automated connections to a variety of spreadsheet, visualization tools, enterprise data sources such as relational databases and to powerful external programs for statistical analysis and visualization of model results [15]. Repast Simphony allows the user to create model with a visual designer tool or writing the code in Java (the way the authors chose), or any other language that runs on the Java virtual machine. Macal and North [15] reviewed ABM softwares, ascertaining how Repast has a steep learning curve but it is definitely one of the most powerful.

3.2 Model assumptions

In order to develop a model as close as possible to the reality, several assumptions have been made.

The starting position of the agents is decided stochastically, except for some of the security agents and aircraft crew who are, respectively placed near the security controls in the airport (as well as shown in the airport's map) and on their seat on the plane.

Agents exist within a virtual environment discretized into a two-dimensional grid of square cells, each one represents an element in the real world with a size of 0.5x0.5 m^2, according with the average agent dimensions (diameter values) adapted from the Smith's research (table 1) [16].

Agent	Minimum	Maximum
Men	40	48
Women	35	45
Children	30	38
Average	35	44

Table 1: Dimensions of human width [cm] (Adapted from [16]).

The agents' speed values are reported in table 2, according with Smith at al [16]. In normal health conditions an agent moves with a random speed chosen in the range [1.05-1.60] m/s, if the agent is injured (considering it as a person with motion disabilities) it is characterized by a range speed of [0.6-1] m/s.

Agent	Minimum	Maximum
Men	1.10	1.60
Women	1.05	1.45
Injured	0.57	1.02

Table 2: Evacuees speed [m/s] (Adapted from [16]).

Each agent type is characterized with a level of energy and a rest time, both chosen stochastically in a range, in order to simulate the tiredness during the escape. Each of them, indeed, during the run toward the emergency exit when is to tired to keep running has to stop for while in order to recover. The agents who have the ability to shoot, can hit the target only in range and with a certain probability, both these two proprieties can be set at the beginning of the simulation. Moreover, when an agent got shot, it can be wounded (seriously or slightly) or killed.

Repast's time conception passes in discrete steps, defined as "ticks". The tick counter starts at 0 and goes up 1 at a time. In the model 1 second corresponds to 3 ticks, since if moving with an average speed of 1.3 m/s, according to the Smith's conditions [16], agents can move through 3 grid cells in one second.

4 THE HUMAN BEHAVIOR MODEL

The human behavior is a complex mechanism influenced by culture, attitudes, emotions, values, ages, perception and many other aspects. Furthermore, it is important to classify the context and the situation in which analyze it.

In an evacuation scenario, the main factors which influenced the behavior of an individual are:

- *crowd behavior*: individuals in a crowd behave in such ways that have been studied and classified. These behaviors are mostly influenced by kinship, aggregation phenomena or collision events;
- *individual behavior*: which considers the emotional aspects of a person, this is the most variable and unpredictable aspect.

4.1 Crowd Behavior

Human crowd is both complex and fascinating social phenomenon. Sometimes a crowd of people shows well-organized structure and demonstrates a great constructive power, but also people in a crowd seem to abandon their social norms and become selfish, this dual aspect represents clearly the complexity of this phenomenon. In recent years, researchers have applied the different approaches, separately and in combination, to study crowd evacuation under various situations. A crowd behavior model describes how an agent interacts with the others.

According to Vreugdenhil at al. [17] the model considers some of the main crowd behavior aspects: walls and obstacles avoidance, attraction from group of agents and the tendency to move toward the emergency exits.

Furthermore, when agents are stuck in a bottleneck, trying to approach the door in order to escape, they cannot move at the speed defined in the software, but they must wait their turn to pass, simulating the queuing behavior.

The main agent types are the aircraft passengers and the security agents (or aircraft crew). The first type has an incomplete knowledge of the area, then they explore the environment in order to find the emergency exit. The security agents, instead, can reach the emergency exit walking the shortest path, then their first task is to help the other agents to escape, reaching the best exit.

During the simulation, at each time step, the agent collects information from the environment for his decision making process and for elaboration data. The agent, for example, can recognize the presence of the emergency exit, a security agent or a threat on its way, the agent can also identify an injured person with his own level of injury or a group of people.

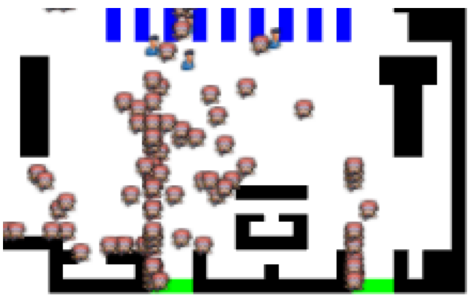


Figure 2: Queuing behavior: agents make a queue, when the door is overcrowded, waiting their turn to pass.

Both the passengers and the security agents are provided with a *memory module*. Respectively, the fist in order to find an emergency exit and the last looking for passengers to rescue, explore wisely the environment, remembering the path they have already walked and then focusing more on that part of the environment not visited yet.

Exclusively when the agents find an exit or a security agent to follow, they reach their final goal walking the shortest path, calculate using the A^* algorithm.

4.2 A* algorithm

A^* is a heuristic search algorithm which allows to find the optimal paths (shortest path) between points in a map even in presence of walls and obstacles. Thus, the algorithm permits to the agents to avoid the obstacles on their path.

This algorithm achieves better performance by using heuristics to calculate the distance from any point on the grid to the destination square, a heuristic function is a technique designed for solving a problem more quickly than classic methods. Thanks to this reason A^* is faster than other more classic approaches such as Dijkstra's algorithm or the Lees algorithm [6]. The increased efficiency of the A^* led the authors to this choice.

The model's environment is discretized into a two-dimensional grid of cells. A^* is a graph search algorithms work on weighted directed graphs, sets of nodes connected by edges that have numeric weights (movement costs) attached to them. Therefore, since a grid can be viewed as a special case of a graph, the first step to implement the A^* in the agent-based model was to convert the grid into a graph where each cell in the grid is a node and in which there is an edge between any two adjacent cells that are not obstructed from one another. The heuristic used is the Manhattan distance function on a square grid.

Moreover, in order to take into account the presence of a crowd, the authors modified properly the algorithm, of course it is not possible to have more than one agent in the same space. In the model, indeed, an agent cannot move in an adjacent cell where is already present another agent, then A^* process is repeated until a new path is determined avoiding the obstacle. Furthermore, the modified algorithm allows the agent to avoid the imminent threat, such as a robber, moving in a place far from it.

4.3 Individual behavior and panic model

The individual behavior in this research has been modeled using the BDI (Belief-Desire-Intention) paradigm. This is the most powerful and easy model to implement because it imitates easily the human reasoning and decision-making process and it is simple to understand by a real human. The BDI was invented by [7] and it describes human practical reasoning and actions in everyday life using programming language, in order to develop intelligent agents. It has been successfully applied in several applications, many medium-to-large scale software systems including air-traffic management system [8]. The systems based on the BDI are able to imitate the human reasoning and decision-making process, moreover, this let the system be easily understood by a real person [9].

BDI, essentially, provides a mechanism for separating the activity of selecting a plan from the execution of currently active plans. Therefore, agents are able to balance the time spent pondering on what to do and doing it. In Bratmans theory, an agent divides its thinking time between deliberating about its intentions, and planning how to achieve those intentions.

Thus, this paradigm bases its foundation on three main concepts:

- *Beliefs*: which are information that the agent currently thinks true, but can be false, but belief does not correspond to knowledge, thanks to this first concept the dynamic nature of the agent's information about itself and the environment can be represented;
- *Desires*: which are the agent's goals, goal deliberation is the process of generating a consistent set of goals, selecting from a set of desires;
- *Intentions*: are the instances of a plan, an agent can have many plans, intention deliberation means choosing a goal that the agent will carry out.

In this research a modified version of the Belief, Desires and Intentions has been used [11]. Zoumpoulaki et al. enriched the classic BDI framework with the incorporation of Personality and Emotions [[11]], as shown in Figure 3

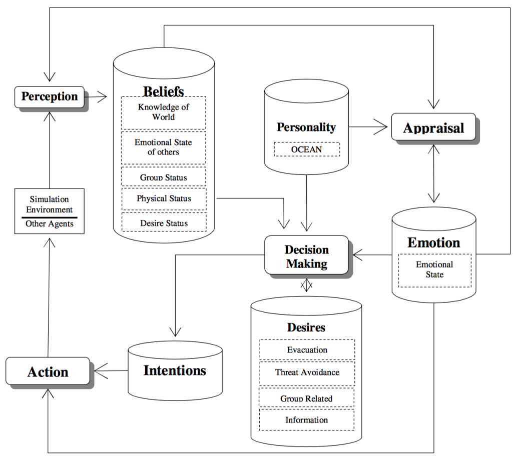


Figure 3: Depiction of Zoumpoulaki BDI framework (adapted from [11]).

The Decision Making Module is the core of a BDI. This module is implemented through the *Decision Field Theory* developed by Busemeyer [12] which was subsequently extended by Lee [9]. The extention allows to updates in the model, under the dynamic environment, the ”subjective evaluation” and the ”attention weights” for the alternatives. This approach provides a probabilistic and dynamic mathematical method to simulate human deliberation process in making decision under uncertainty. It is dynamic because the time is a factor affecting the decisions as well as the changing of environment.

The Decision Field Theory allows to calculate the evolution of preferences among n number of options expressed by an agent over time using the linear system formulation expressed in the Equation 1:

$$P(t+h) = S \cdot P(t) + C \cdot M \cdot W(t+h) \tag{1}$$

where:

- $P(t) = [P_1(t), P_2(t), ..., P_n(t),]$ is an n-element vector that represents the *preference state*;
- S is the *stability matrix*, which represents the memory effect of the preference from the previous state in the diagonal elements, and the effect of interactions among the options in the off-diagonal elements;
- $P_i(t)$ is the probability corresponding to option i at time t, h is the time step;
- C is the *contrast matrix* comparing the weighted evaluations of each option;
- M is the value matrix, (nm), where n is the number of options, and m is the number of attributes, this represents the subjective evaluations (perceptions) of a decision-maker for each option on each attribute. If the evaluation value changes according to the environment, the matrix M is constituted with multiple states.
- W is the weight vector $(mx1)$, where m is the number of attributes;
- $W(t+h)$ values are randomly chosen from a preference interval that is calibrated through a survey

The first member of the equation provides the memory effect. It is the product of the preferences chosen at the previous state $P(t)$ and the stability matrix S.

The framework adopted in this research is a simplification of the model proposed by Lee [9], because of the difficulty of having a good precision for the M matrix calculation.

$$P(t+h) = S \cdot P(t) + T \cdot W(t+h) \tag{2}$$

where T is the condensed matrix CxM.

In this way the matrix T can be easily calculated, before starting the simulation, thanks to the 3 where the vector W_{avg} represents the average values of the W vector intervals.

$$W_{avg} = S \cdot W_{avg} + T \cdot W_{avg} \tag{3}$$

At each step of the ABM simulation, the probability is calculated through Equation 2, with a $W(t+h)$ vector that is randomly defined every time.

In a panic situation a person behave in a impulsive way, without following the rules described above, each decision is led by the instinct. In this condition, each action is not influenced by history and memory, then, the agent's probability to act in such a way can be chosen randomly, following the simple equation 3.

$$P(t+h) = W(t+h) \tag{4}$$

4.4 Panic model

Modeling the panic this research aims to simulate anxiety making choices, under a certain level of pressure, typical of an emergency situation like those simulated in this model. The anxiety can be expressed through the definition of a confidence index, defined as a function of the deviation between what is predicted about the environment during the planning stage and the actual environment during the execution stage [10]. If the confidence index is above a fixed threshold (agent in confident mode), the decision maker performs all his tasks as planned, otherwise the agent re-plans the next step every time before executing a task (agent in suspicious mode).

The proposed agent-based model integrates the confidence index definition, proposed by Cimellaro at al. [14], combining the Lee [10] and Li [13] models in the equation 5:

$$CI_t = (1-\alpha)\left[\beta e^{\gamma\frac{t}{\bar{t}}} + \left(\frac{1-\beta}{2}\right)e^{-d_t} + \left(\frac{1-\beta}{2}\right)e^{\gamma\frac{p}{\bar{p}}}\right] + \alpha CI_{t-1} \tag{5}$$

where:

- $0 \le \alpha \le 1$ is the memory coefficient;
- t is the actual value of time;
- $\bar{t}$ is the characteristic value of evacuation time;
- p is the density of people (agents) around the considered one;
- $\bar{p}$ is the threshold of people density; if the actual p is higher than that value this will lead the person in panic;
- γ is a model coefficient;
- β is the weight coefficient, it describes the influence of the perception of the evacuation time in an agent during the simulation and it is identified by the equation 6.

$$\beta = \frac{t}{\bar{t}}e^{\gamma\frac{t}{\bar{t}}} \tag{6}$$

This confidence index equation takes into account the agents estimation of evacuation time and also the correlation between density of agents and the possibility to see the emergency exit.

Cimellaro et al. [14] developed a human behavior model for emergency evacuation, calibrating the BDI equations managing the data of a surveying activity. Both BDI and confidence index parameters are implemented in this research thanks to the results achived by Cimellaoro et al. [14].

The individual model leads the agents to choose to behave in such a way or another, depending on their preferences, which are influenced by the agent's health status (an agent can be not injured, slightly or seriously injured), by their position in the environment (seeing or not the emergency exit may lead to different choices) and furthermore there is a differentiation between agents in group or alone.

5 CASE STUDY

During this research the authors focused their attention on the evacuation from on airport's terminal, drawing inspiration from the Fiumicino Leonardo da Vinci International Airport in Rome, and on an aircraft, the Airbus A380-800 of Lufthansa's air fleet. Both the airport and aircraft maps are available, respectively, on the Roma's airports and Lufthansa websites.

In the course of the simulations, a special attention was payed on the airport's terminal 3, already affected by a fire accident in the 2015 during the night between the 6th and 7th of May.

5.1 Case study 1: International airport terminal

Information regarding the airport system, because of security matter, are confidential. Therefore, due to the lack of precise information about the Fiumicino Airport's planimetry, the virtual environment investigated in the model traces the line of the building's shape, focusing especially on the security controls' dislocation, but the measurements do not reflect the real ones. The depictions 4 and 5 show respectively the real planimetry of the Terminal 3 (departures and arrivals) and a screenshot from the simulation in Repast. The dimensions considered are 100 m long and 50 m wide. In the Repast map all the emergency exits are represented with green color, the security controls are in blue and the security agents first positions in yellow.

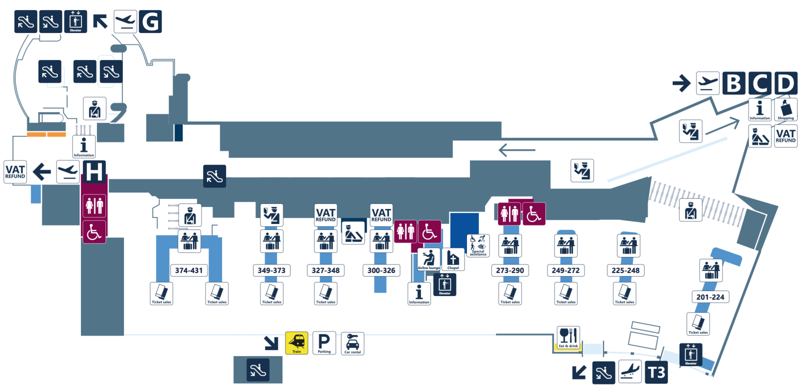


Figure 4: Fiumicino International Airport in Rome: Terminal 3, Departures gate.

Below are reported some results of a simulation performed in the Departures Terminal. The initial number of passengers is set to 400, and they are placed stochastically, at the beginning of the simulation, the security agents are 14, all automatically placed near the security controls.

The figure 8 shows the comparison between the evacuation performed using only the shortest path approach, assuming that everyone in the environment know exactly emergency exits'dislocation in the map and the one using the full model, assuming that the passengers farther from the doors need to start looking for them before heading straight to the exit. It is evident how the first approach underestimate the time necessary to finish the evacuation. The results achieved with the full model are closer to the typical target evacuation time t_m=2.5 min, spec-

Figure 5: A screen-shot from the simulation in the airport terminal.

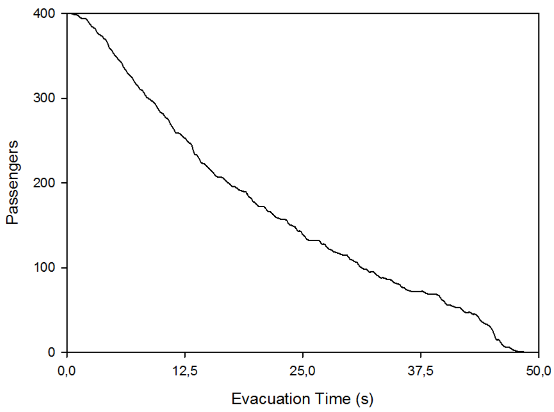


Figure 6: Airport terminal case of study: evacuation using only the shortest path approach.

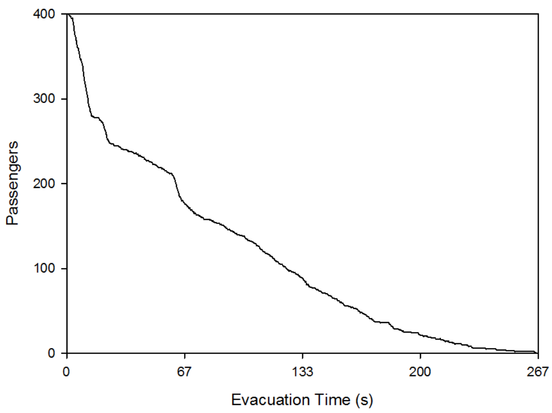


Figure 7: Airport terminal case of study: evacuation using the full model.

ified during the evacuation planning [18]. The results, moreover, show that the first part of the evacuation time is crucial, since the most of the passengers use to escape during that period, this results is reasonable, because the fist people able to escape are the ones closer to emergency exit, seeing the exit as soon as the evacuation starts, they can immediately escape, of course the passengers farther need more time to find the right path.

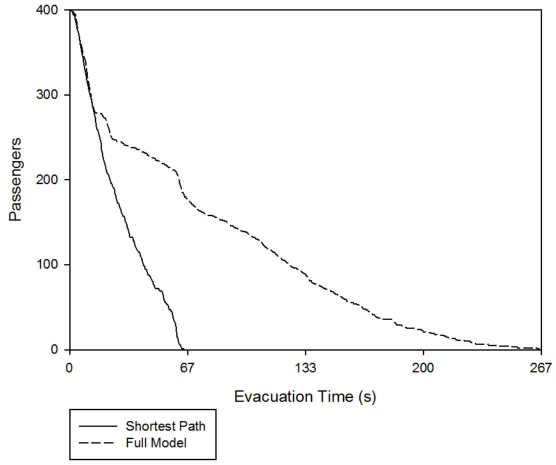


Figure 8: Case of study 1 - Airport Terminal: comparison between the evacuation times, obtained with the full model and just using the shortest path algorithm.

Following figures show the results obtained changing two main parameters, number of security agents and number of robbers, in order to asses their effect on the evacuation.

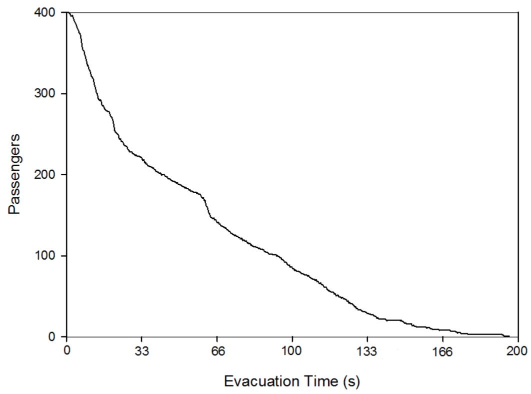


Figure 9: Airport Terminal: evacuation performed with 50 security agents.

The graphs in figure 9 presents the simulation run with an higher number of security agents, compared with the former solution it shows how the increasing number of rescuers, use to reduce the evacuation time.

Figure 10 shows an expected result, the increasing number of assailants use to make increase the number of agents (both passengers and security agents) that fail to evacuate, being killed during the attack.

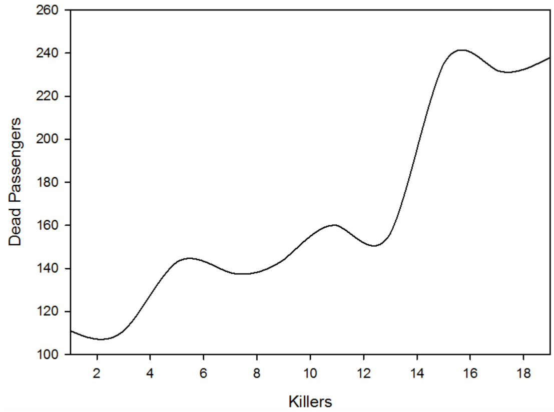
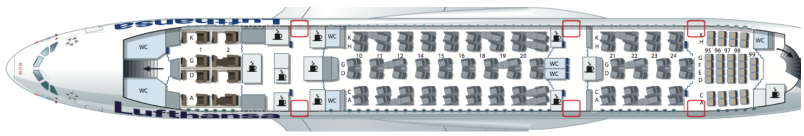


Figure 10: Effect of the increasing number of killers on the dead.

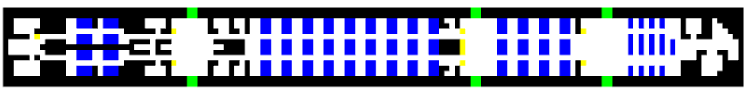
5.2 Case study 2: Airbus A380-800

The examined Airbus A380, presents three different classes (first, business and economy). The main deck consists of 43 seat rows and two main aisle, instead the upper one consists of 20 seat rows and the same number of aisle. In condition of full load, the aircraft can host 402 passengers in the main deck and 107 in the upper deck. The dimensions considered are 72 m long and 7.5 m wide. In the Repast version all the emergency exits are represented with green color, the passengers seats are in blue and the crew seats in yellow.

The depiction below (11) shows both the real plan of the aircraft's upper deck and the discretized version in Repast. The simulation was conducted in a full load condition (107 passengers) and with 10 members of the aircraft crew.



(a) Upper deck.



(b) Upper deck in the repast model.

Figure 11: Airbus A380-800 upper deck seats map.

The figure 12 shows a screenshot of the evacuation from the upper deck, due to a fire in cabin. It is possible to visualize that the agents on the left side are entrapped because of the fire that block the first two exits on the left, the others can evacuate using the remaining doors before that the fire could reach them.

A comparison between the simulation run using both the full model and only the shortest path is also shown in the graph 13. It is evident that the time difference in this case of study in reduced, if compared with the one in the Airport Terminal. This result is expected and appears reasonable, because the aircraft is smaller than the airport, then the space to explore and the

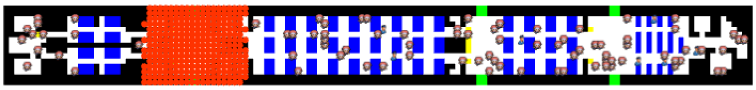


Figure 12: Evacuation from the Airbus A380 upper deck: fire in cabin.

paths to evaluate are drastically reduced. Furthermore, the bigger number of exits is critical in order to perform a faster evacuation.

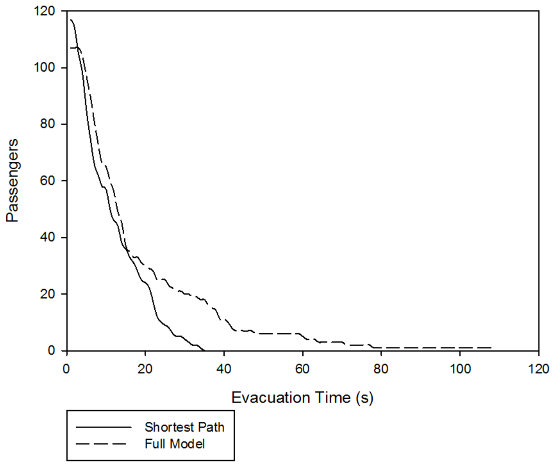


Figure 13: Case of study 2 - Airbus A380-800: Comparison between the evacuation times, obtained with the full model and just using the shortest path algorithm.

6 CONCLUDING REMARKS

The paper aims to propose a new ABM framework for simulations of infrastructure's evacuations, under emergency, providing a decision support in a real emergency scenario in order to study the dynamics of evacuations. The model implements a pedestrian model in order to simulate the crowd behavior and an individual module simulating rational and irrational human behaviors. A memory module was also introduced in order to create agents able to wisely explore the environment. The model takes into account the most important actions typically performed during an evacuation: the seeking of the best way to escape, avoiding an imminent hazard, the leader-follower behavior and the research of a missing person, helping who is in need.

There are two fundamental approaches in literature in order to simulate infrastructures evacuation. The first scenario is when the agent knows the exact series of shortest paths to take to evacuate the building, the other scenario is when the agent does not know the shortest path, the evacuee are in an unknown environment, that they need to explore it first. The authors, thorough this research aim to combine this two approaches. Results show that simulation that rely only on a shortest path algorithm to develop the pedestrian model within the agents-based simulation, use to determinate an underestimated evacuation time. Because they assume that everyone in the building is perfectly aware about the environment map. Combining the environment exploration with the shortest path calculation, which presupposes a good knowledge about the infrastructure to evacuate, the research aim to develop a model closer to reality.

The simulations show that the presence of security agents and their increasing number influence the evacuation. This might be used to evaluate the number of rescue personnel necessary to perform an efficient evacuation. Results also show that, when the hazard occurs, the first part of the evacuation time is crucial, since the most of the passengers use to escape during that period, this results is reasonable, because the fist people able to escape are the ones closer to emergency exit, seeing the exit as soon as the evacuation starts, they can immediately escape, of course the passengers farther need more time to find the right path. This agent-based framework aim to be a comprehensive model, useful to easily evaluate different situations, indeed, thanks to the way it was designed the model can be easily adapted to other scenarios, the authors will use this model for further investigations in the future.

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