Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 130 (2018) 10–17

Procedia Computer Science

www.elsevier.com/locate/procedia

The 9th International Conference on Ambient Systems, Networks and Technologies (ANT 2018)

Agent-Based Modelling and Simulation for evacuation of people from a building in case of fire

Selain Kasereka[a,c,d,*], Nathanaël Kasoro[a], Kyandoghere Kyamakya[b], Emile-Franc Doungmo Goufo[c], Abiola P. Chokki[d], Maurice V. Yengo[a]

[a] University of Kinshasa, Mathematics and Computer Science Department, Artificial and Business Intelligence Lab, Kinshasa, DR. Congo
[b] Alpen-Adria-Universitaet Klagenfurt, Institute of Smart Systems Technologies, Klagenfurt, Austria
[c] University of South Africa, College of Science, Engineering & Technology, Department of Mathematical Sciences, Florida, South Africa
[d] Vietnam National University, Institut Francophone International, Hanoi,Vietnam

Abstract

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, but also of the type of people or the evacuation place configuration. Thus, it is crucial to think on how to organize the evacuation upstream for a situation of emergency can give rise disorganization, on one hand because of panic which grips evacuees, and on the other end because of the large quantity of evacuees in dangerous conditions. These recent years, several fire evacuation models have been proposed. Unfortunately, most of these models do not clearly define the parameters to be considered for their effective evaluations. These models consider, more generally, the number of survivors as a key parameter of evaluation. The purpose of this paper is to propose an intelligent Agent-Based Model enabling the modelling and simulation of evacuation of people from a building on fire. Our proposed model is based on four parameters that allow her practical evaluation. A case study of simulation is carried out in a building having the general configuration of Kinshasa supermarkets. This model is general enough for it to be implemented in several types of commercial buildings without major changes.

Peer-review under responsibility of the Conference Program Chairs.

Keywords: Modelling; Simulation; Fire; Evacuation; Intelligent Agents; Evaluation parameters.

* Corresponding author. Tel.: +243 82 18 28 964
E-mail address: selain.kasereka@unikin.ac.cd

1877-0509 © 2018 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the Conference Program Chairs.
10.1016/j.procs.2018.04.006

1. Introduction

More and more, fire is the cause of human losses in the world. In[1] authors present several examples: in December 2001, 291 people killed during the burning of the commercial center of Mesa Redonda in Lima (Peru). The burning of the hospital in Moscow (Russia) killed 46 people on December, 9 2006. The burning of Santika Club in Bangkok (Thailand) killed 66 people on January, 12 2009. The burning of the day-care center of ABC killed 47 people in Hermosillo (Mexico) on June, 5 2009. At least, 117 people were killed during the burning in the town of Dhaka (Bangladesh) on June, 3 2010. In California, 36 dead people in the burning of a building occupied by a group of artists in December 2016 and recently, in June 2017, the burning of a tower in London caused the death of 17 people and brought about numerous missing people. And that list keeps on growing in an exponential way. Considering these catastrophes, and the human losses, there are grounds to ask questions on the reliability of the evacuation systems applied. When a building is in fire, the evacuation of people raises a certain number of problems. When people get panic, it can even cause numerous victims. Thus, it is important to think about the prevention of risks. In a real life situation, it takes a lot of means, in terms of equipment and even of people, to simulate a building evacuation. The modelling of this situation with intelligent agents and the simulation with a computer program is an interesting thing to do which will help to understand and predict a case of fire without altering the environment.

2. Definition of key concepts

2.1. Intelligent agents

Several definitions relating to agents have been presented by different authors. In[2,3], an agent is defined as a computer system located in an environment and able to accomplish autonomous actions in order to reach its aims in that environment. In[4,5,6], the agent perceives its environment, acts autonomously, interacts to share the aims, constraints, etc., anticipates and reacts with flexibility with its environment and learns from its experiences and adapts to its environment. According to[3,7,8,9,10,11], an agent is a physical or virtual entity able to act in an environment. This agent can communicate directly with other agents; which is driven by a set of tendencies; which possesses its own resources; that is able to perceive (but to a limited degree) its environment; which has only a partial representation of that environment (and eventually none); that possesses competences and offers services.

2.2. Model

A model is a mathematical, graphic and computerized representation of the objects and the relations between them in a confined zone of the real world[2,3]. A model can also be viewed as a simplified representation of a complex reality. To be useful, models must be adapted to theirs objects and be conveniently studied and validated[5,7,12].

2.3. Modelling and simulation

Systems composed by a large number of individuals submitted to several environmental variations, which interact between them and with their environment, like the evacuation of a building in case of fire, where the people evacuated must make decisions quickly, avoid obstacles, choose a nearest exit door, get panic, etc.: these are complex and dynamic systems[9,13,14,15,16,17]. As a whole, modelling and simulation first of all consist in the designing of a model. It is a way of making explicit the complexity of a system in order to better understand its functioning and to make good decisions. It brings the complex system to experiment without altering it too much, often difficult in real life situations[9,18,19]. It enables the system to be accessible at the level of its structure (description) and of its functioning; it tests the hypotheses put up (validation), to have new hypotheses (discovery), and predict its functioning if its structure is changed (prediction).

3. Related works: some existing models

3.1 Evac[19]

Evac is a free evacuation system under GPL license which allows the joint simulation of evacuation and fire propagation. The decisions of individuals are recapitulated by the steps of the algorithm below: (1) Choice on the preference criteria of the exit category; (2) Optimization of expected time up to the exit, for the exits of the chosen category; (3) Propagation simulation of incompressible fluid in order to determine the path to follow; (4) Followed by the field of vectors thus generated with navigational, social and instinctive behaviors (fear of fire and smoke). The decisional model is characterized by the selection of the preference exit category according to the order of preference peculiar to each individual (familiarity, visibility or toxicity at the exit) and time optimization at the exit.

3.2 BuildingEXODUS[3,13,19]

This system being commercial, there is not much information about it. This system is based on statistical models stemming from many experiments and thus represents a very pragmatic approach of the human behavior. Exodus environmental model is presented by the hierarchized partitioning in two levels of abstraction. Each level is represented by: a crude partitioning with convex cells representing the rooms and a regular and thin grid which allows a more precise decision within the rooms. The decisional model of individuals is characterized by the realization of three phases which allows the determination of the best path between a room and the building exit in the graph of the cells. The decision model is quite original, but we note the absence of major factors of evacuation in the simulation: the presence of fire and smoke in the decision. It has been also noted that the physical collisions between individuals are not modelled insofar as the individuals do not covet a cell already taken on the environment.

4. Materials and methods

4.1. Materials at our disposal

a. Intelligent agents

For the realization of this modelling - simulation, we have created a few intelligent agents presented in the table below:

Table 1: List of the intelligent agents created

Agents	Functionalities
« evacuees»	Represents the people inside the building on fire. In the simulation, the number of evacuee agents is taken between 10 and 300. The general speed of evacuees is taken between 0 and 3.6 km/h. The maximum speed is taken between 10 km/h and 25 km/h.
« fire »	Represents the fire. In the start of simulation, the initial location of the fire is random.
« smoke»	Represents the smoke created by the fire. the smoke depends on the fire and moves at a speed defined between 0.1 and 1.0 meter/s.
« alarm »	Represents the fire alarm. The localization of the alarm is fixed. We have defined its smoke perception range at 5 meters.

b. Simulation tool and programming language

There are several simulation platforms of multi-agent systems; in this work we used the GAMA Platform. This platform allows the modelling and the spatially explicit agent-based development (use of SIG data)[1,20]. In the framework of our researches, we have written programs in the GAML (GAma Modeling Language). GAML is an agent-oriented language which enables the definition of simulations on agents.

4.2. *Methods used: Modelling*

a. Definition of hypotheses

Eleven hypotheses need to be clarified for our modelling -simulation: (1) The fire starts at the beginning of simulation ; (2) The fire starts at a point chosen at random on the environment (building) and spreads with a certain propagation speed; (3) In the beginning of fire, the smoke must move in the building; (4) The agents

« evacuees » must have the capacity of escaping, of avoiding obstacles (solid objects or the other agents « evacuees »); (5) The agents « evacuees » shall start the evacuation when they are seeing directly the fire or the smoke, or when they hear the alarm sound, or even if they see a person who evacuates the place; (6) Each agent « evacuee » has potency, expressed by a number that we have taken at random between 50 and 100. During the evacuation, that potency will decrease if the agent is affected by the fire or smoke; (7) When the potency of the agent « evacuees» reaches zero, the agent passed away; (8) When an agent reaches one of the exit doors, he/she is considered as being outside of the building and that moment out of danger; (9) The alarm sets on if the smoke reaches its range. The alarm must stop ringing after a given time; (10) The agents « evacuees» must avoid the fire and be able to change their direction if the fire is in their direction ; (11) The agent « evacuee» has an initial speed which reaches its maximum when he (she) is facing danger;

b. Definition of the evacuee agent navigation on the environment

Several studies have been carried out to model the behavior of humans during evacuation and several models of navigation of the agent evacuated on the environment exist[13,15,21,22,23,24,25]. As part of our research, we propose a navigation model based on the algorithm of the shortest path (Dijkstra). Figure 1 below, depicts the route of the agent evacuated to achieve his goal of reaching the emerging exit closest to his current position while avoiding obstacles (solid objects, other people) and fire. This corresponds to the complete satisfaction of the problem because the agent has evacuated the building.

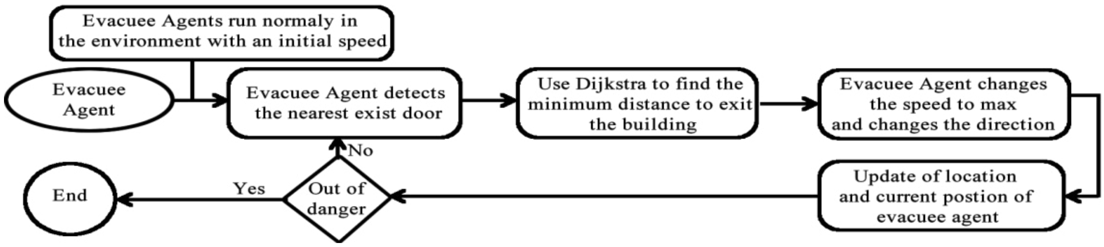

Fig. 1. Navigation of the agent evacuee on the environment to get out and be safe

c. Description of model

Table 2: Agents: their states, perceptions, actions and behaviors

Agent –Based Model (ABM)				
Agents	States	Perception	Action	behavior
« evacuee s»	- alive - in motion - dead - motionless	- fire - smoke - alarm - obstacles - evacuees - doors - passages	- run towards one of the doors - avoid obstacles - die	- when the agent sees the fire or smoke, he/she shall run towards the nearest exit door; - when the agent hears the sound of the alarm, he/she shall run towards the nearest exit door; - when the agent is in the fire range, his/her potency decreases; - when the agent sees a person who evacuates the place, he/she shall run towards the nearest exit door.
« Fire»	- stop propagation - affect the evacuees	- evacuees - obstacles - passages	- spread - created smoke - affect the evacuees	- the fire starts at the beginning of simulation and spreads with time - At the beginning of fire, the smoke must be created.
« smoke »	- propagate	- fire - evacuees - obstacles - passages	- spread in the building - affect the evacuees	- when the fire starts, the smoke propagate in the building.
« alarm »	- ringing - not ring	- smoke	- ring - stop ringing	- when the smoke reaches the range of the alarm, its shall ring. - after some time, the alarm must stop ringing

d. Diagram class

The intelligent agents used in the proposed model are recapitulated in the class diagram shown in Figure 2 below. This diagram presents the attributes and functions to be implemented in the computer program in GAML.

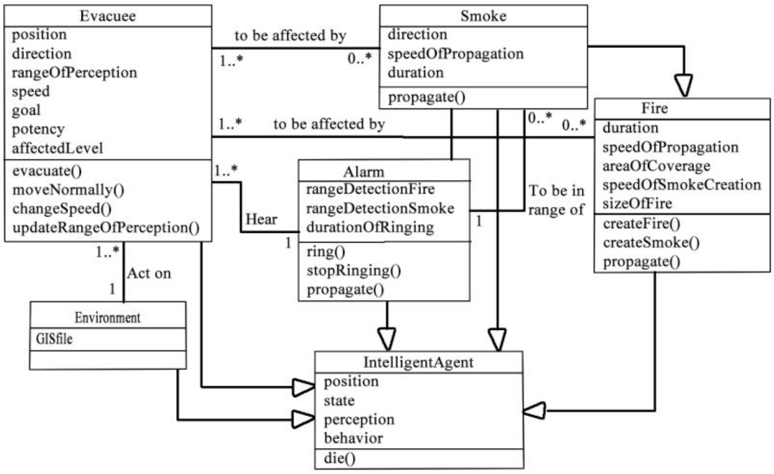

Fig. 2. Class Diagram of the agent-based model proposed

e. Diagram of activities

In this section, we present the modelling of the behavior of the agent evacuee on the environment. During evacuation, the purpose of the evacuee agent is to leave the building by the nearest possible exit door (Figure 3a). In fact, each evacuee agent has a potency that symbolizes his force or his energy (a random number between 50 and 100). This number is attributed to each evacuee agent at the beginning of the simulation (Figure 3b). Once the agent is affected by the fire or smoke, her potency is decrease by a random value taken between 0 and 1. Once the individual power becomes less than or equal to zero, the agent evacuated will die if he/she is not yet out of danger.

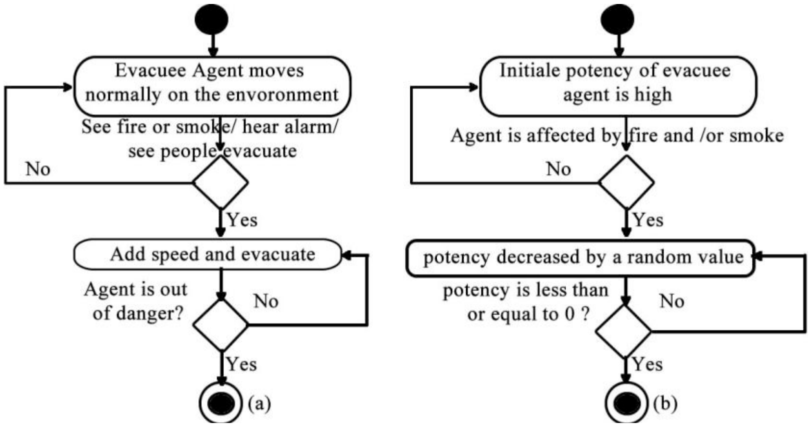

Fig. 3. Activity diagram witch models (a) the evacuation of agents; (b) the potency of evacuee agents

5. Case study: Simulation

In the purpose to test the robustness of our model, we applied simulations in an environment as a representation of a supermarket. The simulations were reiterated 100 times and we considered the mean value as final results.

5.1. Parameters evaluation of the obtained results

Four parameters below allowed us to make an effective evaluation of our proposed model:

a) The total of people alive (TV): represents the number of people having a potency superior to 0 and who have left the building.

$$\mathrm{TV} = \sum av \quad (1)$$

where ***av*** refers to the alive evacuee agent

b) Total deaths (TM): represents the number of persons with a potency less than or equal 0.

$$\mathrm{TM} = \sum ag - \sum av \quad (2)$$

where **ag** is the agent in general and **av** refers to the alive evacuee agent

c) Average potency of the alive persons (MP): represents the average potency of the evacuated alive agents (who were able to leave the building). It is calculated as follows.

$$\mathrm{MP} = \frac{\sum_{i=1}^{n} pav_i}{\sum av} \quad (3)$$

where ***pav*** is the potency of alive evacuee agent and ***av*** refers to the alive evacuee agent.

d) Average time taken to exit (MT): means the average time taken by an evacuated agent to leave the building. It is calculated as follows:

$$MT = \frac{\sum_{i=1}^{n}(fs_i - ds_i)}{\sum av} \quad (4)$$

where: ***fs*** defines the time which the evacuated agent ends the evacuation alive; ***ds*** represents the time the agent evacuated begins evacuation; ***av*** denote the alive evacuee agent and ***n*** is the total number of alive evacuee agent.

5.2. Simulation of our model

The simulations of our model are presenting in this section. In fact, simulations were made not only to present the functionality of our model but also to allow a better choice of the evacuation plan for the building, using evaluation parameters presented in the previous section. We will vary the values of some parameters and evaluate their impact on our model. The table 3 shows various parameters and the number of simulation done.

Table 3: Simulations carried out and diverse parameters

Simulation number	Various parameters
1	default parameters
2	number of agents evacuated and fire propagation speed
3	speed of evacuees agents
4	ranges of the fire and of smoke
5	the levels of being affected by the fire and smoke

We considered two possible scenarios on a supermarket environment. The first uses the plan shown in Figure 4 below (with two exit doors) and the other scenario is done on an environment with 3 exit doors.

5.3. Results

In the real world, there are several factors involved. That why, for our simulations, we performed for each case 100 experiments and retained the average as the final result of the simulation. The output values are displayed via the GAMA platform. The simulations done are recapitulated in the table 4 below. The simulation numbers follow the variations on the model parameters shown up in table 3:

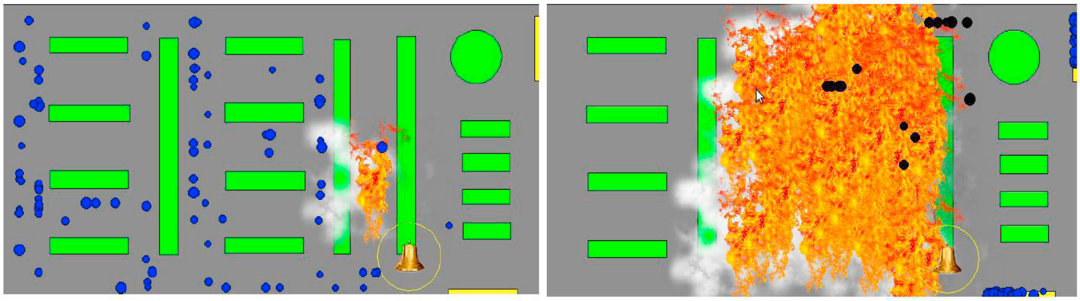

Fig. 4. (a) Simulation of our model under GAMA platform with 80 people in the building on fire and having 2 emerging exits and alarm; (b) Simulation of the proposed model under GAMA platform. Blackheads represent the dead people in the building. The blue points on the exits represent the evacuees that are out of danger.

Table 4: Scenario 1, values of the evaluation parameters of our model (2 exit doors).

Simulation number / Evaluation parameter	1	2	3	4	5
TV	66	515	85	23	56
TM	34	485	15	77	44
MP	38.82	25.58	65.58	26.85	12.23
MT	216.14	785.52	78.25	205.29	241.56

The evacuation takes into account several factors, in particular the obstacles to avoid (objects and other people), the fire and smoke propagation speeds, the speed of people to evacuate, the potency of evacuee people, etc.

Table 5: Scenario 2, values of the evaluation parameters (3 exit doors)

Simulation numbers / Evaluation parameters	1	2	3	4	5
TV	95	725	95	33	66
TM	5	275	5	67	34
MP	67.56	25.58	68.58	56.93	42.34
MT	105.14	785.52	68.86	163.46	181.29

6. Discussion of Results and Concluding Remarks

6.1. General discussion

Based on the results we obtained on the simulations carried out, we note that more the number of evacuee agents is high, more the number of dead people is high too, and also more the evacuation parameter MT is low. This situation can be explained by the missing of way and the presence of jams because of the high number of evacuee people who leaves the building in case of fire. More the speed of evacuee agents is high, more the number of survivors is also high and the TM is low. This can be explained by the fact that with a high speed the agents evacuated reach the door more quickly and manage to get out of the covering zone of the fire and smoke. We have also noticed that the addition of an exit door has influenced our model a lot, there were more survivors and the MT parameter was smaller. This can be explained by the fact that there are several exits to get out of the supermarket. We have to note that, in the simulation, when we added the speed parameter of the fire, it has caused a lot of deaths. It is justified by the fact that the higher speed propagation of fire or smoke affects the potency of the evacuee agents. The variation of the level of being affected by the fire and smoke has an impact on the MP parameter, so when this level is high the MP parameter is very low because the potency of agents was considerably decreased. The covert range of the fire in the environment have also an impact on the TV parameter, when this range is large the TV parameter is very low, this situation can be explain by the effect that many agent are rapidly affected by the fire and die.

6.2. Concluding remarks

We have presented in this paper an intelligent Agent-Based Model to simulate the evacuation of people from a public building on fire. This model made it possible for us to rethink the evacuation plan of a supermarket in case of fire. Our simulations have shown that the presence of several people to be evacuated, the consideration of the fire propagation speed and other factors influence the model a lot. In a real life situation, many factors can be taken into account: emotion, physical handicap, stress, the wind speed, age of evacuees, gender etc. these factors can considerably influence the decisions and actions of the people to be evacuated. In the framework of perspectives, we hope to integrate these by including fuzzy logic into the model. However, we note that our proposed model is general, so that it can be used to several types of commercial building without major changes.

Funding

This work was supported by the Artificial and Business Intelligence Laboratory (www.abil.ac.cd) of the Mathematics and Computer Science Department, Faculty of Sciences, University of Kinshasa in DR. Congo.

References

1. Hung Nguyen M., Ho Toung V. and Zucker JD, Integration of Smoke Effect and Blind Evacuation Strategy (SEBES) within fire evacuation simulation, Simulation Modelling Practice and Theory 36, 2013. DIO: dx.doi.org/10.1016/j.simpat.2013.04.001
2. Axelrod R., The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration, Princeton Univ. Press, NJ, 1997.
3. Wooldridge M., and Jennings N.R., editors. Intelligent Agents - Theories, Architectures, and Language, Volume 80 of lecture Notes in Artificial Intelligence. Springer-Verlag, 1995.
4. Bonabeau E., Agent-based modeling: Methods and techniques for simulating human systems, Proceedings of National Academy of Sciences of the United States of America, Vol.99, No.3, 7280-7287, 2002.
5. Chaib-draa B., Connection between micro and macro aspects of agent modeling, Proceedings of the first international conference on Autonomous agents, ACM, pp. 262-267, 1997.
6. Krishna Kanth B. B. M., Agent-Based Modeling Based Artificial Intelligence Robot For Fire Extinguishing, Int. Journal of Engineering Research and Application, ISSN: 2248-9622, Vol. 7, Issue 7, (Part -10), pp. 38-42, July 2017.
7. Ferber J., Multi-agent systems: an introduction to distributed artificial intelligence. Reading: Addison-Wesley, 1999.
8. Leong S. P., EvacSim: A Simulation Model of Occupants with Behavioural Attributes in Emergency Evacuation of High-Rise Building Fires, Fire Safety Science-proceedings of the Fourth International Symposium. pp. 681-692.
9. Quesnel, Approche formelle et opérationnelle de la multi-modélisation et de la simulation des systèmes complexes. Apports pour la simulation des systèmes multi-agents, PhD thesis, Université du littoral - Cote d'opale, 2006.
10. Wooldridge M., Müller J. P., and Tambe M., editors. Intelligent Agents Volume II-Proceedings of the 1995 Workshop on Agent Theories, Architectures, and Languages (ATAL-95, volume II of Lecture Notes in Artificial Intelligence. Springer-Verlag, 1996.
11. Sharma, S., "Simulation and modeling of group behavior during evacuation", IEEE Symposium Series on Computational Intelligence, Intelligent Agents, March 30-April 2, Nashville, TN, USA, 2009.
12. Lesne A., Biologie des systèmes : l'organisation multiéchelle des systèmes vivants, Médecine Sciences 25, 585-587, 2009.
13. Gwynne S, Galea E R, Lawrence P J, Filippidis L. Modelling occupant interaction with fire conditions using the building EXODUS evacuation model. Fire Safety Journal, 36(4): pp. 327-357, 2001.
14. Helbing D., Farkas I., Molnar P., Vicsek T., Simulation of pedestrian crowds in normal and evacuation situations, in: M. Schreckenberg, S.D. Sharma (Eds.), Pedestrian and Evacuation Dynamics, Springer, Berlin, pp. 21–58, 2002.
15. Sharma S., Avatarsim: A multi-agent system for emergency evacuation simulation, Journal of Computational Methods in Science and Engineering, Volume 9, No. 1,2, pp. S13-S22, ISSN 1472-7978, 2009.
16. Korhonen T. et al., Fire dynamics simulator with evacuation: FDS + Evac technical reference and user's guide, pp. 30–57, 2010.
17. Ogunlana K., and Sharma S., Agent based Simulation model for data visualization during evacuation, ASE BIGDATA/ SOCIALCOM/ CYBERSECURITY Conference, Stanford University, ISBN: 978-1-62561-000-3 May 27-31, 2014.
18. Tang F., Ren A., Agent-Based Evacuation Model Incorporating Fire Scene and Building Geometry, Tsinghua Science and Technology, Volume 13, Number 5, ISSN 1007-0214 21/25 708-714, 2008.
19. Valentin J., Simulation du comportement humain en situation d'évacuation de bâtiment en feu, PhD thesis, Univ. De Pau, 2013
20. Amouroux E., Quang C., Boucher A., Drogoul A., GAMA: an environment for implementing and running spatially explicit multi-agent simulations, in: 10th Pacific Rim International Workshop on Multi-Agents (PRIMA), Thailand, 2007.
21. Botea A et al, Near Optimal Hierarchical Path-Finding. Journal of Game Development, vol. 1, no. 1, pp. 7–28, 2004.
22. Kuligowski E.D.n at al., The need for behavioral theory in evacuation modeling, in: Klingsch W.W.F., Rogsch C., Schadschneider A., Schreckenberg M., (Eds.), Pedestrian and Evacuation Dynamics 2008, Springer, Berlin Heidelberg, pp. 721–732, 2010.
23. Kuligowski E.D., The process of human behavior in fires, Technology 1632. NIST Technical Note, May 2009.
24. Sharma S., Singh, Prakash A., Multi-agent modeling and simulation of human behavior in aircraft evacuations, IEEE Transactions on Aerospace and Electronic Systems, Vol. 44, No. 4, 2008.
25. Veeraswamy A., Galea E.R., and Lawrence P., Implementation of Cognitive Mapping, Spatial Representation and Wayfinding Behaviours of People within Evacuation Modelling Tools. In Proceedings of the 4th International Symposium on Human Behaviour in Fire, pp. 501–512, Robinson College, Cambridge, UK, Juillet, 2009.