Agent-Based Simulation for Coordination Emergency Response: A Review Study

Maha F. Alotaibi
Lecturer, Information Technology Dept.
College of Computer, Qassim University
Buraidah, KSA
atiebymf@qu.edu.sa

Dina M. Ibrahim
Assistant Professor, Information Technology Dept.
College of Computer, Qassim University
Buraidah, KSA
D.Hussein@qu.edu.sa

***Abstract*—this article critically reviews the recent empirical literature on agent-based simulation for coordination emergency response. It provides an indication of the previous research related to coordination in crisis response with agent-based simulation. The goal of this paper is to propose a classification of the literature researches that based on emergency response. Our classification divides the researches into three areas. The first area is coordination in an emergency response, while the second area is coordination of emergency response with agent-based simulation; finally, the third area is agent-based simulation for emergency response. We present and analyze the works in each area supporting our presentation with the famous simulation models. As a result of our classification, we found that those works related to coordination mechanisms between multi agencies in emergency response are not covered well. Moreover, some of the researches still limited in simulating realistic agent behaviors in emergency response.**

Keywords- Agent based simulation; emergency response classification; and coordination.

I. INTRODUCTION

As coordination in general refers to some activities that can be used to manage dependencies [1]. Another view of this definition is evident in Galbraith's work [2, 3] based on uncertainty, which is explained as the variance between the quantity of information required to accomplish a task and the amount of information already influenced by the association. Coordination between different agencies, such as paramedics, fire brigades, and police officers who are dealing with rare and novel events, remains an under researched area [4-6], it is critical for effective multi-agency emergency response during emergency services. Mass-Casualty Incidents (MCI), whether natural or manmade, require fast and sufficient responses, in the same time different emergency organizations should share different types of resources. Researchers have found that during disaster, the coordination between agencies or emergency responses is not satisfactory due to significant challenges facing the coordination management [7-9]. Agent based simulation provides many advantages to allowing study alternatives of solutions which would help expert to find the best coordination plan for different scenarios.

II. AGENT-BAESD SIMULTION BACKGROUND

Simulation considered as one of the best supporting technologies to help experts make their decisions. In the literature, there are three types of simulation techniques: Discrete Event Simulation (DES), System Dynamics (SD), and Agent Based Simulation (ABS) [10]. DES is a top-down modeling approach focused on modeling all the systems in detail. The system has a set of entities that are processing and evolving over time by ordered event [10]. In practice, an event comprises a specific change in the system's state at a specific point in time. SD simulation takes a top down approach by modelling system changes over time where individuals within the system do not have to be highly differentiated. The analyst has to set the key state variables, which determine the behavior of the system. While ABS is "a computational methodology that allows the analyst to create, analyze, and experiment with artificial worlds populated by agents that interact in non-trivial ways" [11], it is bottom up modeling approach where the focus is on modeling the agent, entities, and the interaction between them. Agent-based simulation became a popular way to model different applications, such as illustrated in the work of [12] for traffic and transportation engineering; and to study crowd evacuation, as represented in [13].

ABS is one trend in emergency response. Simulation by computational tools provides a safe learning environment and offers advantages in allowing investigations of multiple scenarios that would be expensive or impossible to recreate in real life to evaluate different co-ordination approaches [14] [15]. Moreover, ABS have the ability to provide a natural description of emergency response, agent, with its ability to interact with their environment and to other agents [16]. In addition, simulation of emergency responses used as a part of preparedness assists in testing methods, training participants, and validating procedures. Finally, the simulation training events help people in forming theoretical mental models to support them in new situations [17].

Emergency response situations face many problems, such as gathering information and changing on demand. The ABS agent has the ability to perceive and explore its environment, exchange information, make decisions, and adapt its behaviors for this decision, where DES and DS do not. For this reason, ABS is well suited to simulate emergency response emergency response [18,

978-1-5386-4427-0/18/$31.00©2018 IEEE

19]. The characteristics of ABS reinforce using it for modeling the actions of the responder. It is considered advantageous and more accepted than other simulation techniques because it takes into account agent behaviors, agent heterogeneity, communication, and co-operation emergency response [18]. In particular, the coordination emergency response team has to consider all issues that face the emergency response work and adopt their work based on modifications to the rescue plan.

There are many architectures that have already been used to model emergency responders' behavior, such as decision trees [20], genetic programs [21], Belief-Desire-Intention (BDI) [22], and Finite State Machines (FSMs) [23]. In order to handle the agents' states changing and their adopted behaviors, FSM is appropriate to modelling agent behaviors [23, 24] [18]. According to Hawe *et al.* (2015), in this work, they introduced that at any time the emergency responder achieves one of a limited number of activities, a FSM can use only one state at any specific time. Moreover, due to an event an emergency responder can change the state, according to the changing in the environment [18].

After reviewing many research papers, we found that it is suitable to classify the literature review according to emergency response into three areas. The first area is coordination in an emergency response, while the second area is coordination of emergency response with agent-based simulation. Finally, the third area is agent-based simulation for emergency response, as in Fig. 1, and the articles that study agent based simulation for emergency response. In our point of view, this article will be classified literature review as follows:

- Coordination in an emergency response.
- Coordination of emergency response with Agent Based Simulation.
- Agent Based Simulation for emergency response.

Next tree subsections will explain of details each of them supporting with the important research in this field.

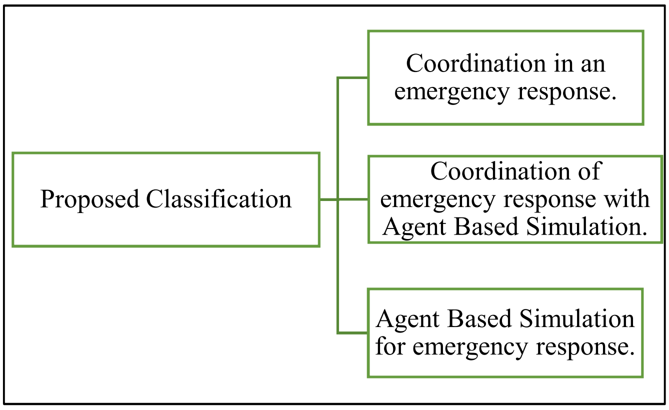

Figure 1. The proposed classification areas of emergency response based on literature review.

A. *Coordination in an Emergency Response*

Coordination is critical for effective multi-agency emergency response during emergency services which need to adapt quickly to a complex event [6]. It is often cited as one of the main problems facing coordination management teams in crisis response due to the significant challenges; for example, unexpected events, time pressure, distributed resources [4], technical constraints [25], and information management [26]. An extension framework of Malone and Crowston's theory of coordination is presented in [27], where participants shared goals, that deals with goal conflicts before any (collaborative) coordination mechanism is put in place. Also, authors in [28], proposed three layers for coordination support that take into account management of conflict. These two studies deal explicitly with collaboration to avoid resources competing and different priorities at different times between participants during a crisis.

Mass-casualty incidents MCI, whether natural or manmade, require fast and sufficient responses, different emergency organizations should share different types of resources . During the process of crisis response, the existence of adequate information can improve.

Coordination output and response action in disaster management are presented in [29]. In terms of an information view, the information should be collected and gathered between others as much as possible before the actual disaster occurs [30], which means that accurate and timely information is critical in crisis response [31]. In addition, organisations should have the ability for information exchange, search, and adaptation [32, 33].

In research [34], the authors argue that past coordination models, which are focused on managing resources [1], are insufficient to work with a dynamic environment and there is a need for flexible and informal structure to facilitate the management of skills and knowledge interdependencies in organizations where decisions should be made quickly without errors. Kling *et al.* suggest theoretical perspectives in addition to the information processing view to understanding the dynamic organizational problems [35]. Their work has improved the coordination of crisis response organizations because they focused on interconnection of distinct groups more than on a plan or standard for information processing to deal with a dynamic environment [23].

In order to solve these issues, an agent based simulation using geographic information systems (GIS) is used in some reserch to investigate different coordination mechanisms and represents all emergency services, i.e., firefighters, police officers, ambulance vehicles, and casualties.

B. *Coordination of Emergency Response with Agent Based Simulation*

This section provides an indication of the previous research related to coordination in crisis response with agent-based simulation. For example, authors in [36] tested the global partial global planning (GPGP) approach in an emergency medical information system, which is based on the scheduling task of agents and improves distribution and heterogeneity. Authors in [37] developed disaster response information flow and Technology Simulation to model the flow of information in a crisis event, which can assess different types of information technologies for disaster response. In 2006, [38] present multi-agent simulation to assess different rescue plans and [39]

978-1-5386-4427-0/18/$31.00©2018 IEEE

proposed DrillSim, project which is based on a multi-agent simulation to show the importance of information management during a disaster.

The work of Skinner and Ramchurn, [40], is considered as a part of the RoboCup Rescue project in the form of an urban earthquake scenario, it present different features including a dynamic environment with limited and uncertain information, limited communication and processing time. Fig. 2 shows the platform design [40]. STORMI is another ABS presented in [18] for an emergency response with resource allocation. In their work, they develop a series of experiments, and with each experiment they vary resource allocations and casualty distribution between the accident sites, see Fig. 3 [18]. Authors in [14] proposed a centralized rescue model for a large-scale environment to help persons with disabilities.

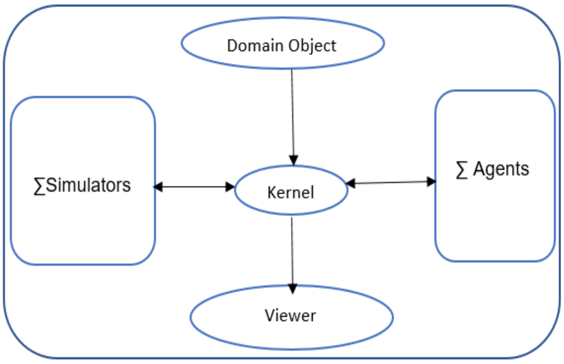

Figure 2. Platform architecture [40].

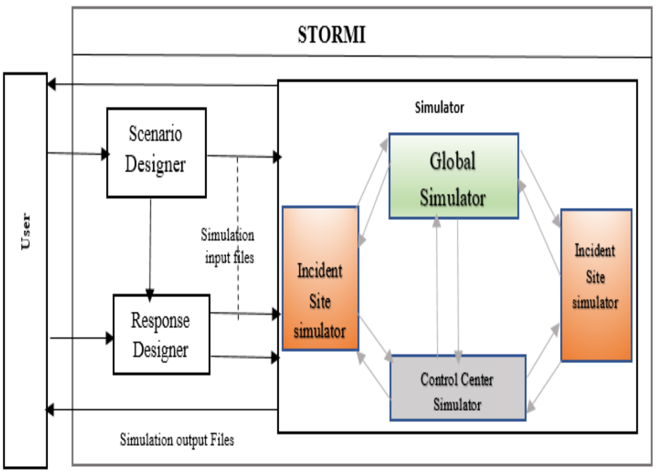

Figure 3. STORMI environment [18].

In research introduced in [6], the authors proposed a decentralized agent-based approach for resource allocation to deal with an emergency event in an urban environment . Most of these systems discuss agent-based simulation in emergency response. Nevertheless, the focus of those works is limited in relation to coordination mechanisms between multi agencies in emergency response. However, an investigation of the coordination mechanisms in ABS (CrisisCoordSim) is explicitly illustrated in [23]. This work is still limited to simulating realistic agent behaviors in emergency response. Moreover, he mentioned the need for additional scenarios to be developed to test various coordination policies.

C. Agent Based Simulation for Emergency Response

This section discusses some research related to an Agent Based Simulation in general, without reference to coordination between agents. Computation methods have become more popular to study an infectious disease outbreak such as influenza. For example, Kim et al. [41] presented a multi-agent model to mimic the spread of Avian Influenza (AI) in various environments in a given population [19] proposed an agent-based modelling method that integrates geographic information systems (GIS) to simulate the spread of influenza in an urban environment, as a result of individuals' interactions in a geospatial context. Another example, in research [42] the authors present a multi-agent based model to simulate individuals' interactions in Egypt to understand the effect of different control strategies on the disease spread using a GIS environment.

Another ABS is Planning with Large Agent Networks against Catastrophes (PLAN-C) for emergency planning and urban disaster simulation, which is used to simulate and evaluate variations of a hypothetical Sarin attack on Manhattan Island in New York City [11], and a food poisoning outbreak in Minas Gerais, Brazil [43]. Mysore et al. simulate food poisoning that happened in Brazil in 1998.

As part of Autonomous Robots for Observation of Urban Networks after a Disaster (AROUND) project, the work in [44] developed a rescue based model on the GAMA platform (GIS (road network) and Agent-based Modeling Architecture to provide an environment for simulations. BioWar is an agent based model of the impact of a bioterrorist attack on a city that combines computational models of social networks, communication media, and disease transmission with demographically resolved agent models, urban spatial models, weather models, and a diagnostic error model, see Fig. 4.

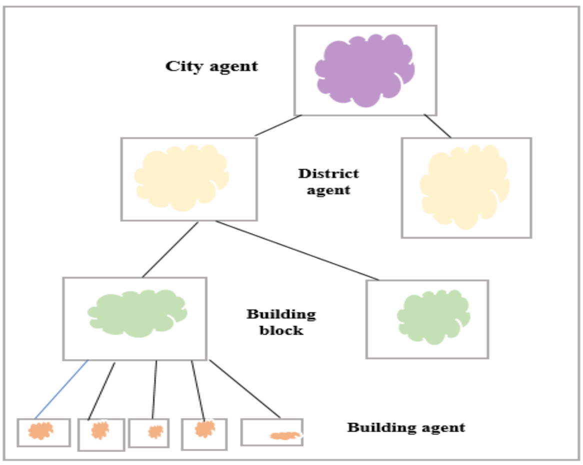

Figure 4. Abstraction heirarchy level [44].

Furthermore, EpiSimS is another ABS for a large-scale emergency response, which uses distributed memory parallelism. In Dell Valle *et al.*, it simulates the daily routines of 16,106,535 individuals in Los Angeles, which modelled as a graph consisting of 562,452 locations representing households, small neighborhoods, workplaces, and schools. Each individual has a set of activities, Fig.5 show the generation of model files, which are required for run configuration [45].

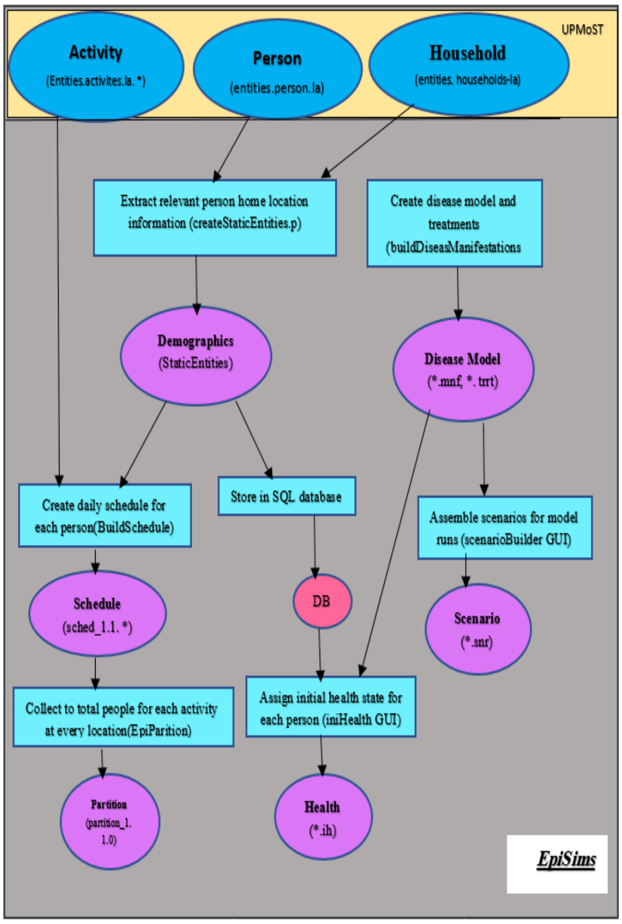

Figure 5. Model files for generation [45].

After studying the three subsections above, there are important ABS works, such as those presented by [38] [40] [39] [36] [37] [18] [14]. Most of these systems discuss agent-based simulation in emergency response. Nevertheless, the focus of those works is limited in relation to coordination mechanisms between multi agencies in emergency response. However, authors in [23] investigate the coordination mechanisms in ABS (CrisisCoordSim) explicitly. This work is still limited to simulating realistic agent behaviors in emergency response. Moreover, it mentioned the need for additional scenarios to be developed to test various coordination policies. Finally, authors in [6] presented coordination mechanisms by resource allocation. However, they did not provide concrete solutions for handling concurrent emergency events.

III. CONCLUSION

As there are important agent-based simulation works, most of these systems discuss agent-based simulation in emergency response. Whereas, the focus in relation to coordination mechanisms between multi agencies in emergency response is limited. In addition, simulating realistic agent behaviors in emergency response should expanded with handling concurrent emergency events. In this paper, we found that it is suitable to classify the literature review according to emergency response into three areas. The first area is coordination in an emergency response, while the second area is coordination of emergency response with agent-based simulation. Finally, the third area is agent-based simulation for emergency response

REFERENCES

[1] T. W. Malone, and K. Crowston, “The interdisciplinary study of coordination,” ACM Computing Surveys (CSUR), vol. 26, no. 1, pp. 87-119, 1994.

[2] G. Jay, Designing complex organizations: New York, Addison-Wesley, 1973.

[3] J. R. Galbraith, “Organization design: An information processing view,” Interfaces, vol. 4, no. 3, pp. 28-36, 1974.

[4] R. Chen, R. Sharman, H. R. Rao, and S. J. Upadhyaya, “Coordination in emergency response management,” Communications of the ACM, vol. 51, no. 5, pp. 66-73, 2008.

[5] T. Meum, and B. E. Munkvold, “Information Infrastructure for Crisis Response Coordination: A Study of Local Emergency Management in Norwegian Municipalities,” in Proceedings of the 10th International ISCRAM Conference, 2013.

[6] J. Zhang, M. Zhang, F. Ren, and J. Liu, “A Decentralised Multi-Agent System for Emergency Resource Allocation in Metropolitan Regions,” in Proceedings of the 2016 International Conference on Autonomous Agents & Multiagent Systems, 2016, pp. 1482-1484.

[7] K. Banipal, “Strategic approach to disaster management: lessons learned from Hurricane Katrina,” Disaster Prevention and Management: An International Journal, vol. 15, no. 3, pp. 484-494, 2006.

[8] R. S. Ruichen, H. R. Rao, S. J. Upadhyaya, and C. P. Cook-Cottone, “Coordaination emergency response,” Information Systems for Emergency Management, pp. 150, 2014.

[9] S. Curnin, C. Owen, D. Paton, and B. Brooks, “A theoretical framework for negotiating the path of emergency management multi-agency coordination,” Applied ergonomics, vol. 47, pp. 300-307, 2015.

[10] P.-O. Siebers, C. M. Macal, J. Garnett, D. Buxton, and M. Pidd, “Discrete-event simulation is dead, long live agent-based simulation!,” Journal of Simulation, vol. 4, no. 3, pp. 204-210, 2010.

[11] G. Narzisi, V. Mysore, L. Nelson, D. Rekow, M. Triola, L. Halcomb, I. Portelli, and B. Mishra, “Complexities, catastrophes and cities: Unraveling emergency dynamics,” in International Conference on Complex Systems (ICCS), 2006.

[12] A. L. Bazzan, and F. Klügl, “A review on agent-based technology for traffic and transportation,” The Knowledge Engineering Review, vol. 29, no. 03, pp. 375-403, 2014.

[13] N. Wagner, and V. Agrawal, “An agent-based simulation system for concert venue crowd evacuation modeling in the presence of a fire disaster,” Expert Systems with Applications, vol. 41, no. 6, pp. 2807-2815, 2014.

[14] K. Arai, and T. Eguchi, “Realistic Rescue Simulation Method with Consideration of Road Network Restrictions,” 2015.

[15] J. Reason, “Human error: models and management,” Western Journal of Medicine, vol. 172, no. 6, pp. 393, 2000.

[16] E. Bonabeau, “Agent-based modeling: Methods and techniques for simulating human systems,”,in Proceedings of the National Academy of Sciences, vol. 99, no. suppl 3, pp. 7280-7287, 2002.

978-1-5386-4427-0/18/$31.00©2018 IEEE

[17] C. Macal, and M. North, “Introductory tutorial: Agent-based modeling and simulation,” in Proceedings of the 2014 Winter Simulation Conference, 2014, pp. 6-20.

[18] G. I. Hawe, G. Coates, D. T. Wilson, and R. S. Crouch, “Agent-based simulation of emergency response to plan the allocation of resources for a hypothetical two-site major incident,” Engineering Applications of Artificial Intelligence, vol. 46, pp. 336-345, 2015.

[19] Y. Wang, K. L. Luangkesorn, and L. Shuman, “Modeling emergency medical response to a mass casualty incident using agent based simulation,” Socio-Economic Planning Sciences, vol. 46, no. 4, pp. 281-290, 2012.

[20] T.-Q. Chu, A. Drogoul, A. Boucher, and J.-D. Zucker, “Interactive learning of independent experts' criteria for rescue simulations,” J. UCS, vol. 15, no. 13, pp. 2701-2725, 2009.

[21] A. Runka, “Genetic programming for the RoboCup Rescue simulation system,” 2011.

[22] A. H. Pereira, L. G. Nardin, A. A. Brandao, and J. S. Sichman, “LTI agent rescue team: a BDI-based approach for Robocup Rescue,” Proceedings of RoboCup, 2011.

[23] R. A. González, “A framework for ICT-supported coordination in crisis response,” TU Delft, Delft University of Technology, 2010.

[24] A. Braun, B. E. Bodmann, and S. R. Musse, “Simulating virtual crowds in emergency situations,” in Proceedings of the ACM symposium on Virtual reality software and technology, 2005, pp. 244-252.

[25] S. Shen, and M. Shaw, “Managing coordination in emergency response systems with information technologies,” AMCIS 2004 Proceedings, pp. 252, 2004.

[26] S. J. Rietjens, H. Voordijk, and S. J. De Boer, “Co-ordinating humanitarian operations in peace support missions,” Disaster Prevention and Management: An International Journal, vol. 16, no. 1, pp. 56-69, 2007.

[27] C. Lewis, R. Reitsma, E. V. Wilson, and I. Zigurs, “Extending coordination theory to deal with goal conflicts,” Coordination theory and collaboration technology, pp. 651-672, 2001.

[28] M. Klein, “Coordination science: Challenges and directions,” Coordination technology for collaborative applications, pp. 161-176, 1998.

[29] L. K. Comfort, K. Ko, and A. Zagorecki, “Coordination in rapidly evolving disaster response systems: The role of information,” American Behavioral Scientist, vol. 48, no. 3, pp. 295-313, 2004.

[30] T. Bui, and A. Tan, “A template-based methodology for large-scale HA/DR involving ephemeral groups-A workflow perspective,” in System Sciences, 2007. HICSS 2007. 40th Annual Hawaii International Conference 2007, pp. 34-34.

[31] B. Van De Walle, M. Turoff, and S. R. Hiltz, Information systems for emergency management: Routledge, 2014.

[32] N. Bharosa, J. Lee, and M. Janssen, “Challenges and obstacles in sharing and coordinating information during multi-agency disaster response: Propositions from field exercises,” Information Systems Frontiers, vol. 12, no. 1, pp. 49-65, 2010.

[33] L. K. Comfort, and N. Kapucu, “Inter-organizational coordination in extreme events: The World Trade Center attacks, September 11, 2001,” Natural hazards, vol. 39, no. 2, pp. 309-327, 2006.

[34] S. Faraj, and Y. Xiao, “Coordination in fast-response organizations,” Management science, vol. 52, no. 8, pp. 1155-1169, 2006.

[35] R. Kling, K. L. Kraemer, J. P. Allen, Y. Bakos, V. Gurbaxani, and M. Elliott, “Transforming coordination: The promise and problems of information technology in coordination,” Center for Research on Information Technology and Organizations, 2001.

[36] W. Chen, and K. S. Decker, “The analysis of coordination in an information system application–emergency medical services,” in Agent-Oriented Information Systems II, 2005, pp. 36-51.

[37] C. D. Robinson, and D. E. Brown, “First responder information flow simulation: a tool for technology assessment,” in Simulation Conference, 2005 Proceedings of the Winter, 2005, pp. 7 pp.

[38] N. B.-B. Saoud, T. B. Mena, J. Dugdale, B. Pavard, and M. B. Ahmed, “Assessing large scale emergency rescue plans: an agent based approach,” The International Journal of Intelligent Control and Systems, vol. 11, no. 4, pp. 260-271, 2006.

[39] D. Massaguer, V. Balasubramanian, S. Mehrotra, and N. Venkatasubramanian, “Multi-agent simulation of disaster response,” in First international workshop on agent technology for disaster management, 2006, pp. 124-130.

[40] C. Skinner, and S. Ramchurn, “The robocup rescue simulation platform,” in Proceedings of the 9th International Conference on Autonomous Agents and Multiagent Systems: volume 1-Volume 1, 2010, pp. 1647-1648.

[41] T. Kim, W. Hwang, A. Zhang, S. Sen, and M. Ramanathan, “Multi-agent model analysis of the containment strategy for avian influenza (AI) in South Korea,” in Bioinformatics and Biomedicine, 2008. BIBM'08. IEEE International Conference on, 2008, pp. 335-338.

[42] K. M. Khalil, M. Abdel-Aziz, T. T. Nazmy, and A.-B. M. Salem, An agent-based modeling for pandemic influenza in Egypt: Springer, 2012.

[43] V. Mysore, O. Gill, R.-S. Daruwala, M. Antoniotti, V. Saraswat, and B. Mishra, “Multi-agent modeling and analysis of the brazilian food-poisoning scenario,” in The Agent Conference, 2005.

[44] P. Taillandier, D.-A. Vo, E. Amouroux, and A. Drogoul, “GAMA: a simulation platform that integrates geographical information data, agent-based modeling and multi-scale control,” in International Conference on Principles and Practice of Multi-Agent Systems, 2010, pp. 242-258.

[45] S. Y. Del Valle, P. D. Stroud, J. P. Smith, S. M. Mniszewski, J. M. Riese, S. J. Sydoriak, and D. A. Kubicek, “EpiSimS: epidemic simulation system,” in Los Alamos, NM: Los Alamos National Laboratory, 2006.

978-1-5386-4427-0/18/$31.00©2018 IEEE