How Can the RoboCup Rescue Simulation Contribute to Emergency Preparedness in Real-World Disaster Situations?

Tomoichi Takahashi[1(✉)] and Masaru Shimizu[2]

[1] Meijo University, Shiogamaguchi, Tempaku-ku, Nagoya 468-8502, Japan
ttaka@meijo-u.ac.jp

[2] Chukyo University, YagotoHonmachi, Showa-ku, Nagoya 466-8666, Japan
shimizu@sist.chukyo-u.ac.jp

Abstract. The RoboCup Rescue project is based on the situations that occurred during the Great Hanshin Earthquake in 1995. Various types of disasters occurred after the Hanshin-Awaji Earthquake, and the experiences from managing such disasters has shown that evacuation with prompt and appropriate information at the initial period of the disaster is as important as the rescue operations during the disasters. In this paper, we discuss validation and verification of the agent based systems that can simulate the behaviors of individuals and collective evacuation behavior during emergency situations. Collective behavior is difficult to verify by executing evacuation drills in the real world. The effectiveness of evacuation simulations is shown and a plan of experiments at RoboCup venues is proposed to challenge the validation and verification of social simulation and to prove the usefulness of as real-world applications.

1 Introduction

The RoboCup Rescue project was initiated in 1999 to promote research and development related to search-and-rescue operations. The project was initially designed on the basis of the situations encountered during the Great Hanshin Earthquake of 1995 in Kobe, Japan. Since then, there have been many major disasters such as the September 11 attacks (U.S.A., 2001), earthquake off the West Coast of Northern Sumatra (Indonesia, 2004), Hurricane Katrina (U.S.A., 2005), Eastern Sichuan Earthquake (China, 2008), Great East Japan Earthquake (Japan, 2011), and Typhoon Haiyan (Philippines, 2013). The types and causes of these disasters were different; however, saving human lives is a common challenge during and after such disasters.

The potential of robots designed in the Rescue Robot League (RRL) was revealed during the search-and-rescue operations carried out at the World Trade Center [8]. Robots entered areas where human rescuers cannot enter because of adverse environments and transmitted photos from inside the debris formed by the collapse of the buildings. In 2011, robots including QUINCE developed in the RRL were used for search operations inside the Fukushima Daiichi Nuclear Plant that was damaged by a tsunami [1].

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The Rescue Simulation League (RSL) proposed a new application field to facilitate research on issues regarding the agent community [6]. Supporting search-and-rescue operations after a disaster is one of the major purposes of robots that were designed in the initial days of the RSL. During the one and half decades that have passed after the RSL started, the expectations regarding rescue simulations have changed. Experiences from managing the disasters have showed that having an evacuation support system at the initial period of a disaster is as important as having the rescue operation support system. Some projects applied rescue simulation systems to real-world domains including training systems [14].

In this paper, we discuss validation and verification of results that are simulated for situations of future emergencies. New application areas of the agent based rescue systems are demonstrated and the effectiveness of the applications are shown in making prevention plans to save human lives for possible accidents. The remainder of this paper is organized as follows. In Sect. 2, related works are introduced, and it is shown that individual behaviors are modeled in an agent system. Section 3 discusses the verification methods and applications of rescue simulations. The effectiveness of the virtual evacuation drill is discussed as an example in Sect. 4. Finally, a summary is provided in Sect. 5.

2 Background and Applications of Simulation

A disaster can happen at any time and any place. Table 1 lists some major disasters during which many lives were lost and massive rescue operations were launched at the sites. The causes of disasters can be natural or man-made. Fires, building collapses, and tsunami/flood result in the loss of human lives and properties. In the case of earthquakes, there is less time for evacuation than in the case of other types of disasters, even though emergency earthquake alerts are available.

Table 1. Disasters that occurred after the Hanshin-Awaji Earthquake

		Man made	Nature		Cause		ASET
			E. (B. C)	H. (F.)	Fire	Tunami	
1995.1	Great Hanshin E.		√		√		-
2001.9	September 11 attacks	√			√		H
2004.12	W. C. of Northern Sumatra		√			√	-
2005.8	Hurricane Katrina			√		√	D
2008.5	Eastern Sichuan		√		√		-
2011.3	Great East Japan E		√			√	H (for tunami)
2013.11	Typhoon Haiyan			√		√	D

W.C.of Northern Sumatra: Off The West Coast of Northern Sumatra
E.: Earthquake, H.: Hurricane, B.C.:Building Collapse, F.:Flood
ASET (Available Safe-Escape Time): -, H and D represent no time, an hourly basis time and a daily basis time to evacuate, respectively.

The International Organization for Standardization (ISO) published a technical report that specifies the parameters related to the assessment of the conditions of a building's occupants with respect to time [5]. The assessment related to occupants includes the numbers, locations, characteristics, conditions, and so on. The parameters that focus primarily on the evacuation of occupants are the available safe-escape time (ASET) and the required safe-escape time (RSET). For instance, to ensure compliance with the fire-safety guidelines of a building, the ASET should be greater than the RSET. Although making RSET short is an approach different from allocating rescue agents effectively - which the RSL targets -, simulating evacuation times using agent-based simulation (ABS) could play an important role in disaster preparedness and help significantly in saving human lives.

During emergencies, humans behave differently than during usual times. People's mental condition at these times greatly affects their behavior. For example, when people fear for their physical safety, they tend to think of only themselves and would flee from a building without consideration for anything else. Documents released by the National Institute of Standards and Technology (NIST) related to egress from the World Trade Center buildings on September 11, 2001, and reports from the cabinet office of Japan on the manner in which people evacuated during the Earthquake and the resulting tsunami on March 11, 2011, revealed several evacuation behavior patterns: some people evacuate immediately, while others do not evacuate despite hearing announcements made by authorities [3,9]. It is interesting to note that individuals' behaviors were similar to the behaviors of individuals during a flood in Denver, U.S.A. on June 16, 1965, even though communication methods have changed during this intervening fifty years [4]. Approximately 3,700 families were suddenly evacuated from homes. The family behaviors during the flood that occurred following the provision of warnings were categorized as follows: (1) some families evacuated immediately, (2) other families attempted to confirm the threat of disaster, and (3) some families ignored the initial warning and continued with routine activities.

Perry et al. used their study's empirical findings to summarize the influence of these human relationship factors on the decision-making process [13]. Pelechano et al. illustrated that communication among people improved evacuation rates by using an ABS [12]. They devised a scenario that focused on two types of agents: leaders who help others and explore new routes; and agents who might panic during emergencies that occur in unknown environments. Tsai et al. developed ESCAPES, a multi-agent evacuation simulation system, by incorporating four key features: different types of agents, emotional interactions, informational interactions, and behavioral interactions [15]. Okaya et al. proposed a model of information dissemination among people during evacuation and presented simulation results using a large number of people [11].

Human behavior depends on available evacuation times and the number of evacuees involved during emergencies. Evacuation simulations that consider the human factors are assumed to be useful in analyzing the egress behaviors at emergencies and estimating evacuations processes such as ASET and RSET. They are assumed to be useful in design evacuation processes and preparing prevention plans for emergencies. The plans can be checked more properly in estimating the loss of human lives than using simulations without considering the factors.

3 Problems in Estimating Simulations Involving Human Factors

3.1 Estimating Effects of Human Factors on Simulation Results

Reports on the past disasters indicate that human factors; mental status and the amount of guidance what they heard, play important roles at emergencies. It is hoped to execute evacuation drills by changing the conditions that affect human behaviors, however, from the participants safety it is difficult to execute such drills. Evacuation simulation systems provide useful perform to replace the evacuation drills, however, it is hard to verify the results of simulation.

The validation and verification (V & V) problem has been one of the most important issues in simulations [7]. Michel et.al represented the V & V problem in the form of the following questions:

Q1. Does the model accurately represent the source system?
Q2. Does the model accommodate the experimental frame?
Q3. Is the simulator correct?

It is ideal that simulations involving human behaviors are based on theoretical models and the results of simulations are tested against empirical data. At present, we cannot compare the results with real data, but we can improve prevention planning for disasters by using simulations in which many significant factors are represented.

In the RoboCup RSL, teams compete to improve the performance of their rescue agents in various disaster environments. The performance of the rescue agents is evaluated on the basis of how they decrease the damages after the disasters. The parameters of disaster scenarios include the places where earthquakes occur, fire ignition locations, number and locations of agents, and so on. Subsimulations are programmed based on some models of disaster. The parameters of disaster simulations are such as the strength of earthquakes or the spreading speed of fires. The simulation results have not been tested by other methods and the situations are the same as in other evacuation simulations.

In the NIST report, evacuation times were calculated by several commercial evacuations systems. The calculations were crosschecked with the results of each other. The results were obtained under conditions in which all occupants started their egress at the same time. Actually, the simultaneous start of egress is not different from the situations that were presented in the NIST report. ABS provides a method to model such human behavior and can answer the first V & V question (Q1). Qualitative analysis of the simulation results by experts will help to make effective prevention plans without executing real evacuation drills.

3.2 Rescue Simulation to Improve Prevention Planning

The following questions show cases that simulations can be used to save lives for future emergencies.

Information Guidance by New Media. It is reported that the users of the microblogging site Twitter exchanged information during the Great East Japan Earthquake, 2011. Our first question is if Twitter had been available in 2001, would it have been useful in evacuating more people safely from the buildings or how many lives could have been saved at the time of the September 11 attacks.

To answer such questions, a multi-agent system provides a good platform on which a simulation system can be designed. Indeed, it is hard to carry out experiments in real-world situations and show that the simulation results have good V & V support. For instance, simulations can show the difference in the results without/with information diffusion by Twitter. The results can be used to improve the quality of prevention planning during future emergencies.

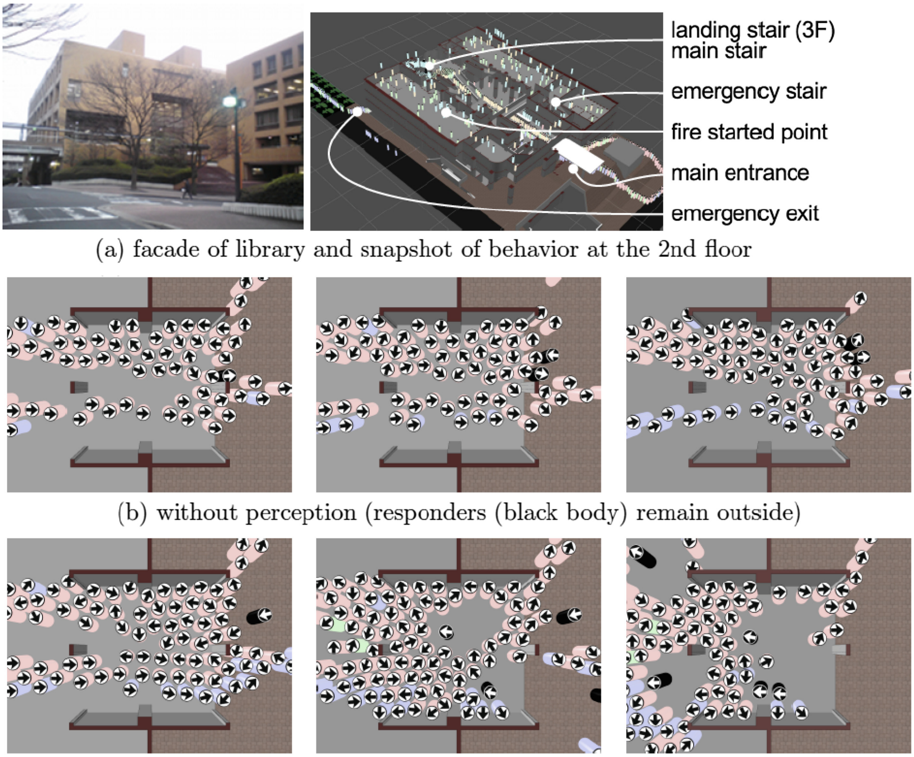
Variety in Evacuee's Behaviors and Guidance at Unfamiliar Buildings. Figure 1 shows two snapshots of Junior League venues at RoboCup 2010 (Singapore) and 2011 (Istanbul). Many families participate in the Junior League. Their evacuation and communication behaviors at the venue would be different from that of people in major leagues with no parent-child human relationships. It is hard to plan safety measures for emergencies against various possible cases even though other conditions such as the number of people are similar ones. In the case of evacuation planning from the venue of events, people are not familiar with the layout of the venue. This also makes it hard to egress smoothly. Our second question is whether RSL can provide an effective tool to save people when emergency occur at the venue of RoboCup or not.

Fig. 1. Snapshots of RoboCup Junior Competition venues (Singapore and Istanbul)

4 Possible Applications and Practical Answers

4.1 Virtual Evacuations Drills for Occupants Egress and Rescue Operations

Evacuation drills are conducted with the goal of ensuring smooth evacuations from buildings and improving the speed of rescue operations at emergency sites. Consider the following scenario: A fire breaks out in a five-story building and



(a) facade of library and snapshot of behavior at the 2nd floor

(b) without perception (responders (black body) remain outside)

(c) with perception (responders move inside against occupants (light color body))

Fig. 2. The simulation of evacuation from a building. (Rescue responders (blue) enter from the right.) (Colour figure online)

evacuation guidance is announced inside the building. One thousand occupants (200 occupants on each floor) evacuate from the building, and a rescue team enters the building to extinguish the fire. Does the rescue team accomplish its mission?

Figure 2 (a) shows the facade of a five-story library building and a snapshot of the agents' behaviors on the second floor. TENDENKO, RoboCup Rescue simulation system based evacuation simulator, was use to simulate the behaviors [10]. Figure 2(b) and (c) show the counterflow of occupants and fire responders at the main entrance. The occupants (light color body with black arrow) egress from left to right and the responders (dark color body with white arrow) enter the building from right. The arrows on the occupants' heads indicate the direction of their movements. The time-sequence is ordered from left to right and the simulation time steps are 40, 45, and 50, respectively. Table 2 shows the number of occupants who evacuated from the building and the number of responders who entered. The difference in simulations (b) and (c) is whether agents have the ability of perception or not.

Table 2. Number of evacuated occupants and entering responders at the main entrance.

Time step	Number of							
	Evacuted occupants				Entering responders			
	without perception		with perception		without perception	with perception		
35	66	(21)	83	(27)	0	0	
40	89	(23)	106	(23)	0	0	
45	109	(20)	113	(7)	0	3	(3)
50	129	(20)	115	(2)	0	5	(2)
55	153	(24)	129	(14)	0	5	(0)
60	169	(16)	148	(19)	0	5	(0)

Numbers in the parentheses are different from the previous step.

In emergencies, people move aside to let the rescue team in. The perception of the other agent's social roles is an important feature required in heterogeneous MAS as well as the functions of agents. We categorize the roles as follows:

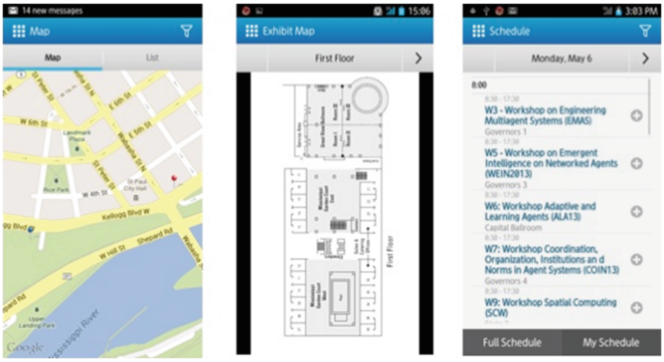
G_g (agents without priority): an agent gives no special considerations to them and the agent expects that no considerations would be made for itself.
G_h (agents with high priority): the agent gives special consideration to them.
G_l (agents with low priority): the agent expects that special considerations are expected from them.

A normal agent gives consideration to the rescuers and the disabled, who are categorized as G_h. For occupants, rescue personnel are G_h agents, whereas the rescuers are categorized as G_g by their colleagues. More occupants evacuate when they do not have the perception than when have the perception. In the case of occupants without perception, the rescue team cannot enter the building against the flow of evacuating occupants. In the case of occupants with perception, the occupants recognize the rescue agents as G_h and make way for the responders to move through the building. The rescue team can therefore enter the building and move to the appointed position in the building.

4.2 Evacuation Guidance in Commercial and Public Facilities

At emergencies, how can we egress from huge buildings where we are unfamiliar with the layout? Smartphones have spread rapidly, and applications (apps) for mobile phones for navigating routes to destinations or guiding people to downtown area are used. An app at the AAMAS2013 conference was prepared for participants by the organizers [2]. Figure 3 shows the displays of the application: the location of the hotel, the floor plan, and the program of the conference from left to right. It was useful for people who were unfamiliar with the layout of the conference hotel to find the rooms they wanted to join.

Figure 4 (a) is a guidance board showing a floor map including the locations of the stairs and fire extinguishers that are of use during emergencies. The board



(a) location of hotel (b) floor guidance (c) program

Fig. 3. Application delivered at AAMAS2013

assists people with alarms or announcements recommending use of the nearest stairs and exit to the outside of the building. The places in which the board is displayed are limited, and it is difficult to inform many people simultaneously of proper guidance during emergencies.

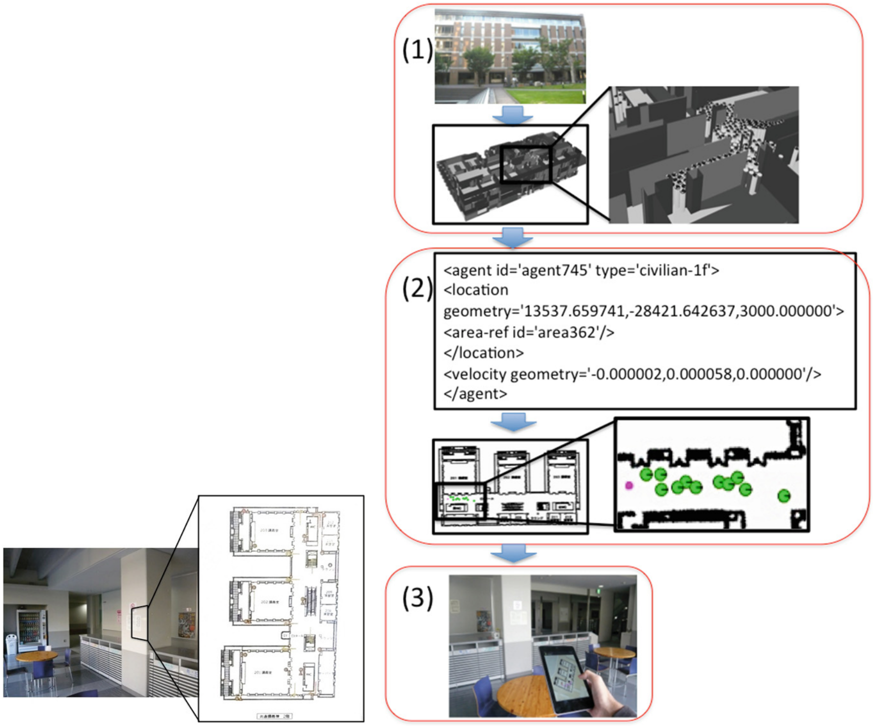
Figure 4 (b) shows one solution to the problem.

1. Authorities simulate the evacuation behaviors during various cases of emergencies. The images at the top row of Fig. 4 (b) are photographs of the behaviors observed during evacuation from a building to the outside. Authorities plan routes for smooth evacuations and prepare guidance menus for the emergencies.
2. The evacuation routes are saved in an XML file and transferred to smartphones with other menus that are used for everyday services.
3. When an emergency occurs, people switch the app to emergency mode. The app displays the exit routes in a same fashion as the event menus. Circles in the image represent people, and the circle movements show efficient evacuation routes.

4.3 Evacuation Drills in Real Lives and by Simulations

Evacuation drills are carried out regularly in real lives. The purposes of the drill are to check the effectiveness of the desk plan and to familiarize the operations required during emergencies. The drills are carried out under the following conditions:

1. Participants in the drills know when the drill will start and how they are expected to behave during the drill.
2. The behaviors of people and the process of rescue operations are scheduled according to manuals that were planned beforehand.



(a) guidanceboard (b) guidance using smartphones

Fig. 4. Evacuation guidance board showing the floor layout including the locations of the stairs and fire extinguishers.

To verify the effectiveness of a given evacuation drill, it is necessary to simulate and analyze movement from the viewpoints of building occupants and the first responders. The concern of occupants is how quickly and safely they can evacuate a building, whereas the first responders are concerned with the ease and efficiency necessary to reach target points and start rescue operations.

The conditions of drills such as the number of people involved, time and weather when disasters occur are different from that of real cases. To verify simulations, the drill data obtained under one specific condition can be used as the experimental data. This limited data can be used as a qualitative characteristic, but not a quantitative characteristic, to verify the simulation results. The drills are useful for verifying the suitability of manuals and the level of emergency preparedness.

5 Discussions and Summary

After RSL started, many types of disasters occurred and new technologies and systems assumed to be useful in emergencies were announced. We expect such technologies and systems to be efficient, and try to utilize them during past disaster to solve the problems that were encountered. For example, through prompt evacuation guidance using new communication media such as Twitters and so on, more lives could be saved during the September 11 attacks and other disasters by guiding reuse teams and people promptly. We showed the counterflow movements between occupants and rescue teams (Fig. 2). The counterflow movements that occurred during evacuation of the WTC buildings at the time of the September 11 attacks are assumed to occur during evacuation from large buildings that contain many occupants.

Agent-based simulations that include human factors such as emotions, human relations, types of behaviors and so on, can simulate the behaviors of individuals more closely to that of real at emergencies; thus the simulation results can support decision making in real-world disaster situations. At present, the evacuation simulations do not have well-grounded theoretical bases, and the results are not verified with experimental data. The experiments themselves are difficult to execute. The V & V of simulations are important for using the results in real-world situations.

RSL provides a great service with its open-source simulation platform. The simulations presented in this paper were executed through a system that is similar to the RSL simulator. The modified parts are the traffic-simulator, the three-dimensional GIS[1], and the agents. The agents are developed to behave as one of three reaction models presented in Sect. 2 and according to the perception model presented in Sect. 4.1.

The next step toward realizing the RoboCup Rescue project for practical use is to solve the V & V problem. We believe that evacuation planning of the RoboCup venue will provide an excellent test bed for the problem, and propose the following timeline.

Approximately two years prior to the RoboCup competition: When the future RoboCup site is established, the three-dimensional model is presented to the community.

Approximately one-half year before the RoboCup competition: Participants prepare evacuations plans using their simulation systems and present their plans to the RoboCup organizations. The organizations select some of the plans with cooperation from local governments.

During the RoboCup competition: The organizations prepare an app that includes the evacuation guide at emergencies, as well as the usual information, such as schedules and a layout of the venue, if possible, the participants rate the guides after experiencing drills at the venue.

Challenging this test bed will answer positively to the questions presented in Sect. 3 and demonstrated the effectiveness of social simulations. We hope participants will join the RoboCup competitions safely.

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[1] RSL targets a decision support for rescue operation at a wide area. Two-dimensional GIS represent the area.

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