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Validation Framework for Simulation of Future Emergencies

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Abstract

Disasters may occur anytime and anywhere in the world. Disaster prevention methods are planned and drills are conducted to mitigate damage and save lives during emergencies. Preparing plans for dealing with disasters of sizes and impacts on civil life that are outside our experience will be effective during future emergencies. However, the simulation data of out-the-box scenarios are lack foundation so it is difficult to apply them to real emergency situations. The situations are same for data driven prevention planning. The validation and verification of social simulations for the hypothetical conditions are important. This paper presents a framework to discuss the problem on validating simulations involving human behaviors and shows that discussion according to how the results will be used is necessary to ensure its validation to the applied field.

Keywords: *social simulation; validation and verification; prevention planning; agent based simulation*

1. Introduction

Disasters may occur anytime and anywhere in the world. Disaster prevention methods are planned and drills are conducted to inspect disaster-related social systems for criteria such as damage assessment, response measurement, and evacuation guidance because these help save lives during emergencies. During emergencies, the authorities activate alarms or announce evacuation instructions to begin evacuations. According to the Great East Japan Earthquake (GEJE) at 2011 report, only 40% of evacuees hear the emergency alert warning given over the PA system [1] [1]. Of those who heard the warning, 80% recognized the urgent need for evacuation.

Drills and prevention planning at non-emergency times are thought to be effective ways to mitigate the damages future emergencies. In December 2015, a university in Nairobi, Kenya executed an anti-terrorism exercise. The drill included the use of gunshots, which caused students and staff to panic. Many people jumped from the university building windows and were injured [2]. Even statutory training in real situations can create risks for disabled people and some vulnerable groups. In social simulations, we cannot perform real life experiments and can also hardly involve humans as a factor in such experiments.

Computer simulations enable the examination of out-the-box scenarios that have not occurred in the real world. Agent based simulations (ABS) can express the microscopic behaviors of humans. In science and engineering, the following steps have been repeated to further their advancement: guess→ compute consequence → compare experiment. However, this steps cannot be used in human behavior related matters. Validating the results of social simulations is critical to ensure their applicability to the real world. Applications involving life-threatening situations, especially, require data from real-world situations to assure their usefulness [3].

[1] The report was based on investigations conducted with 870 people from Iwata, Miyagi, and Fukushima prefectures.

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In this paper, framework for validating the simulations for hypothetical emergencies are discussed. In Section 2, the steps to model phenomena are presented. The manner in which simulation results can be used as decision support tools during emergencies is discussed in Section 3. Section 4 introduces some examples of data usage during emergency situations. Section 5 provides a summary.

2. Modeling of Real World Phenomena

2.1. Modeling of Physical Phenomena

Figure 1 shows the traditional process of modeling phenomena. The phenomena are observed and represented as a data set $Os_i = (s_i, d_i)$ where d_i is the data of the ith observation at situation s_i. Modeling of phenomena involves extracting parameters, c_i and the relationships among the parameters, F_i. The validity of the modeling is checked whether the derived results from F_i, correspond to observed data, d_i [4]. Laws of physics that is empirical science have been derived based on the principle. When new phenomena are observed, more specific laws are developed by adding new parameters, reformulating relationships between them, and so on to achieve higher reliability [5].

Kikuuwe pointed out that two kinds of errors are brought into simulations in robotics [6]. The first type of error is associated with the modeling process and the second type is associated with the computations involved in the model (Figure 2). He enlisted three kinds of parameters:

c_i: parameters that users can control.
e_i: parameters that users do not notice or cannot specify.
n_i: parameters that are introduced in the process of simulations, such as numerical errors and distributed computations.

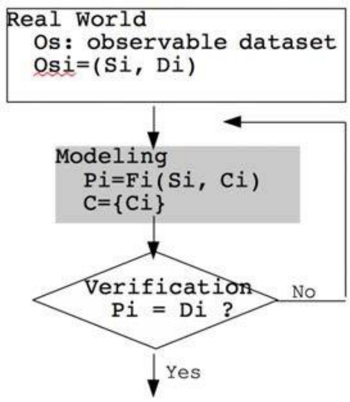


Figure 1. Modeling Process of Physical Phenomena

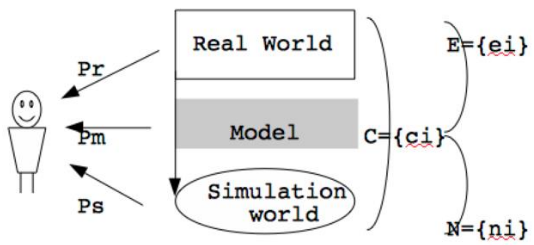


Figure 2. Perception of Phenomena in Three Domains

Think of Buffon's Needle, where the computation of the exact dropped position is hard and requires the determination of many physical parameters. The probability of the dropped needle positions is sufficient to check the validity of the model. He pointed out an idea of a plausible simulation that comes from CG field is formulated such that an occurrence in $P_S(C, N)$, one simulation results, is involved in $P_R(C, E)$ where $C = \{c_i\}$, $E = \{e_i\}$, and $N = \{n_i\}$.

2.2. Modeling of Social Phenomena

Human behavior during evacuation, stock market prices, and others are examples of social phenomena. In the simulations, human behavior is modeled in statistic models, agent based approach and others. Baraski analyzed the bursty natures of human behavior in the queuing process [7]. People behave differently during emergencies; some people evacuate instantly, while other may evacuate only after finishing the tasks [1]. It is difficult to represent the different features of people during emergencies in the statics based simulations.

Using agent technology provides a platform to simulate social phenomena arising from human activities. The micro-specific approach has been accepted to solve complex real world problems in various areas. Jenning et al. proposed a framework called Social Level, in which multi agent systems (MAS) are targeted at systems composed of responsible societies [8]. The responsible society is composed of the following components:

Members: entities performing the problem solving,

Environment: where members are situated,

Means of interaction: the ways members interact,

Goals: a motivational force that drives problem solving among members.

Emergency situations are composed of natural disasters, human behaviors and their interactions. For disaster applications, the RoboCup Rescue simulation system (RCSS) was proposed after the Hanshin Awaji Earthquake in 1995 [9]. The parameters of F_i in RCSS were set to match the simulation results for the damage resulting from the Hanshin Awaji Earthquake. Takahashi summarized the lessons from the RCSS and the requirements for the decision support system (DSS) during emergencies from the local government using the RCSS as an example of DSS [10].

3. Two Usages in Decision Support Process during Emergency

3.1. Simulation based Approach

Figure 3 is an image that ABS will support decision of rescue operations at emergencies. Prevention plans for emergencies are prepared using ABS for various situations that may occur. During emergencies, plans appropriate for situations are selected and related operations are executed according to the plans. These plans will be executed based on changing situations. The process is formalized as follows:

(1) Planning for emergencies during non-emergency times.
(2) Selection of plans at the first stage of an emergency.
(3) Tuning the plans during the emergency according to newly acquired data.

1) Planning during non-emergency time: Emergency situations arise from various causes. The simulations for various cases and scenarios are executed for various disasters such as fire, flood, typhoons, earthquakes, *etc.*, and situations such as the size, the occurrence times, and so on. Figure 4 is the architecture of an emergency simulation system. Each F is a model of a disaster case that is derived according to the process of Figure 1. The superscript corresponds to the disaster and the subscript, the situation.

For example, $F^{fire}_{daytime}$ and F^{fire}_{night} estimate different damages even if the fires occur in the same area of the city. The outputs from F_i are combined into a form, Tp that represents emergency situations raised from various factors. The entanglement is not well formulated and are computed based on some assumptions [11]. The simulation results are estimated and analyzed. The plans to mitigate the damage are examined and are prepared for future emergencies: Find conditions c_i (related to damage) to minimize the damages are calculated from $F(s_i, c_i)$. The c_i and corresponding situations s_i are stored as manual recipes during emergency.

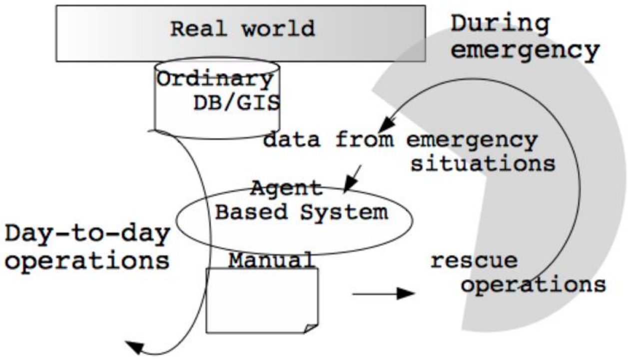


Figure 3. An Image of ABS used by Local Governments

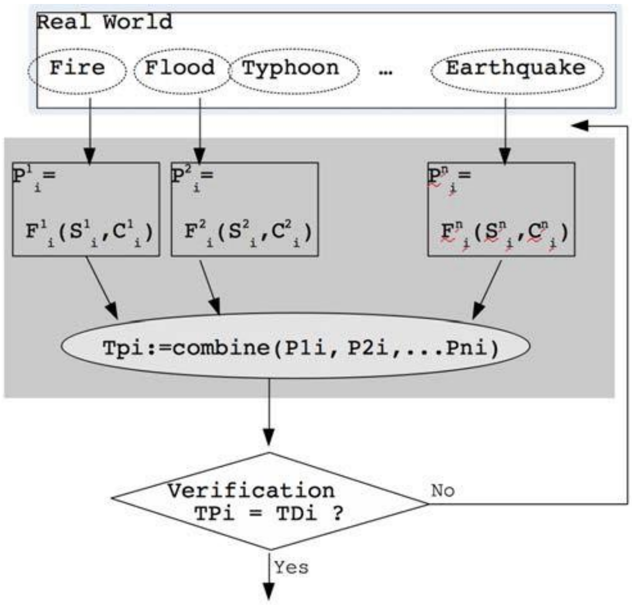


Figure 4. System Architecture of Emergency Simulation System

2) *Performing actions during emergency:* When an emergency occurs, people at the headquarters try to identify the situations and select plans for similar situations from the manuals. They then take actions according to the manuals. When information about the emergency is newly received at the headquarters and the present emergency situation does not fit the situation described in the manual, people refer to the manual for seeking other plans.

3) *Process of hypothetical simulations for unexpected emergencies and its validation:* The process of finding the optimal (best possible) c_i is to simulate and compare $Tp_i(s_i, c_i)$ with $Tp_i(s_i, c_i + \Delta c_i)$ or $Tp_i(s_i + \Delta s_i, c_i)$. The situations and conditions are outside the range of previous ones or are composed of several cases. So we do not have

real world data that the calculations are based on. People at the headquarters find it difficult to take actions related to human lives derived from simulations based on hypothetical situations.

3.2. Case based Approach (Bayesian interpretation)

Given data of past emergencies and data of drills as a data set, $D = \{Ds_i\}$, we predict hypothetical situations and estimate damages from the knowledge gained from emergencies and their size. They are expressed as $P(s_{hyp}|c_i, s_i)$ and $P(damage|c_i, s_i)$. This says that when the disaster is similar to a past situation, s_i that occurs with the conditional c_i and will predict the damage and its probability distributions. They execute a prevention plan that changes c_i to c_k so that the distribution $P(X|c_k, s_j)$ shifts to better one than $P(X|c_i, s_j)$ where X is an index of predictions.

In weather forecasting, many data sets have been used to predict weather; rain, snow, typhoon, and others. The power, size and locations of the weather act on civil life and their predictions have been used to prepare the coming emergent situations, for example, local government announce altering information to people. In fields with less real world data, it is necessary for practical usage to supplement real data with simulated data. This point is the same as the validation issue of the simulation based approach.

4. Categorization of Applied Tasks

4.1. Case studies from the Great East Japan Earthquake

With IT development, systems with new style have been proposed and used to ensure prompt planning for disaster mitigation, risk management for a decade [12][13]. Following examples are three different usages of data at GEJE:

Ex. 1: Car navigation data for open use:

A lot of roads were not motorable due to damage from earthquakes. Car makers provided the data of their car navigation system that showed motorable routes after the disaster. The data helped to deliver relief goods to refugees.

Ex. 2: A tragic case of Ookawa Elementary School with no preparation:

Most students at Ookawa Elementary School were engulfed by the tsunami after GEJE. The school was located 5 km from the sea and hence they did not expect the tsunami to reach the school. That prevented smooth evacuations to safe places.

Ex. 3: Analysis from Twitter data:

Twitter is one of the most influential media, which acts as an information source to many people, help in guidance from local governments of the disaster-affected area, move people to save electricity, and others. After the disaster, logs are analyzed with respect to topics, source-area, and sending time [14].

Table I shows a classification example on the way of data usage. The usages are categorized in two points of view. Stage categorizes when the data is used centering around the emergencies. And data are classified whether the data comes from the real world or the results of simulations. Two examples and Sahana are cases during the emergency times. At the time-critical stage, no cases that simulated data were used are found.

Table 1. An Example of Categorization from Stages of Emergency and Data Source

		usage or	source of data	
stage		application	real data	simulation
before		drill	○	○
		enlightment		
during	I	guidance	○ (ex1)	—
	II	requirement	× (ex2)	—
	I & II	of help logistics	○ (Sahana)[12]	—
after		analysis	○ (ex3)	○
		restortion		

I sufficient time to prepare (eg, typhoon)
II no time for judgement (eg, earthquake)

4.2. What Simulation can Perform in the Future Emergencies

IT have made changes in our everyday lifestyle. In personal communications, many people have used SNS instead of telephones. It is assumed that new media such as SNS will change the evacuation behavior during emergencies. Figure 5 and 7 show the simulation results of evacuation behaviors at a shopping mall by agent based simulation system TENDENKO [15]. 4,039 persons are uniformly in the mall that has 14 exits (Figure 6). And they evacuate according to following scenarios:

scenario 1: A message “evacuate immediately” is announced simultaneously by PA.
scenario 2: pass the evacuation message by word of mouth near people within 10m.
scenario 3: pass the evacuation message through SNS.

The agent’s behavior is programed as

```
if hear the evacuation message
  then with probability p, pass message once.
  else go to the nearest exit.
```

Figures 5 (a) and (b) are the simulation results of p=1.0 and 0.5, respectively. The case of scenario 1 with p = 0.5 corresponds to a situation in which half of the agents remain in the location and do not evacuate even though they hear the announcement from the PA. The behaviors of evacuees correspond to people who evacuate after finishing their jobs and when they fear for their physical safety: these are reported in the GEJE cases [1].

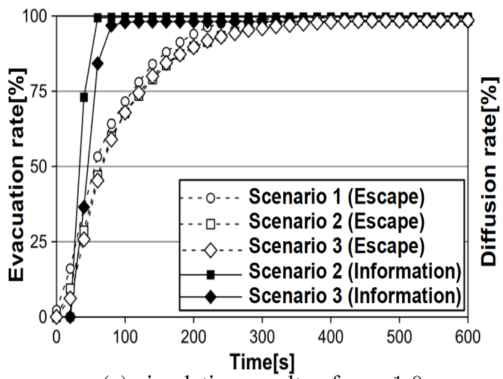
In the scenario 3, the dataset of Facebook data which the number of nodes and edges are 4,039 and 88,234 was used as a connection data in the SNS [16]. Figure 7 (a) shows a distribution of number of connected agents with one edge. The graphs of scenario 3a in Figure 7 (b) are the simulation results of a case that the first messenger is the person who connected with the most agents (in this case 1,045 agents), and the scenario 3b is the results of the first person messenger is connected with one person.

The scenarios, the probability and the who is the first informer are examples of c_i and s_i described in Section 2.2. The graphs with different parameters in Figure 7(b) show the followings:

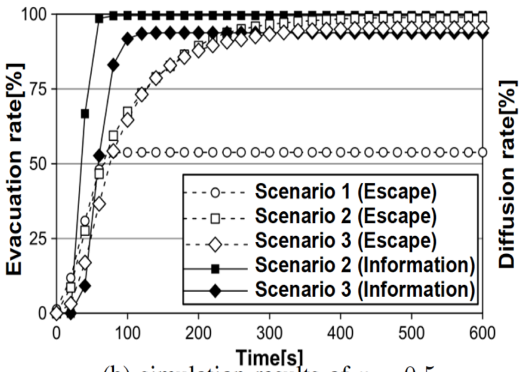
(1) The evacuation rates vary according to the diffusion rate of SNS, and show better results when the first informer is connected to more people.

(2) Owing to the connection of SNS, almost all people are evacuated even in the case where only half of the agents hear the announcement.

The results indicate that a method for guiding people via SNS may result in prompt evacuations to safe places.



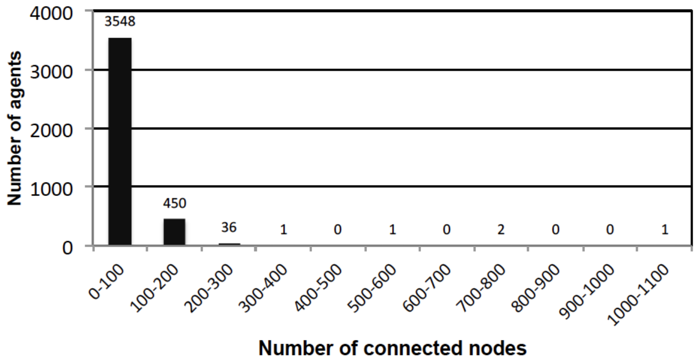
(a) simulation results of $p = 1.0$.



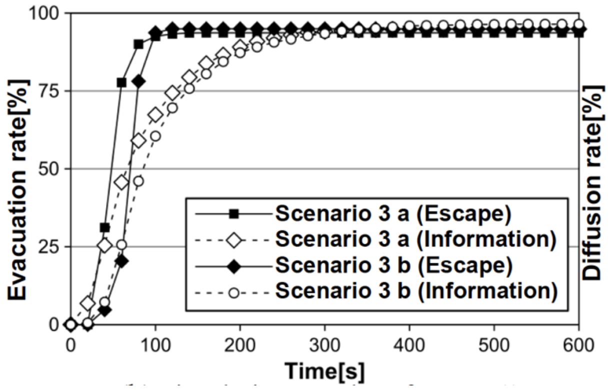
(b) simulation results of $p = 0.5$.

Figure 5. Simulations for Three Scenarios (si) and Diffusion Rates of Information for Scenario 2, 3

Figure 6. Simulation Environment; Shopping mall in Nagoya Station △ is the First Message Point



(a) Distribution of the Number Connected with One Edge



(b) Simulation Result of $p=0.5$

Figure 7. Effect of who Speaks the Message First on Evacuation Behaviors

5. Summary

Preparing plans for dealing with disasters of sizes and impacts on civil life that are outside our experience will be effective during future emergencies. Some standards to check the simulation results for emergencies were proposed to classify the results into two categories: an effective class and mere simulation class [11]. However, the simulation data of out-the-box scenarios are lack foundation so it is difficult to apply them to real emergency situations. The situations are the same with data driven prevention planning. The validation and verification of social simulations for the hypothetical conditions are open problems.

This paper presents a framework to discuss the validation and verification problem of simulations involving human behaviors. Evacuation behaviors are discussed in terms of the simulations executed under the conditions where evacuations are guided through traditional PA and SNS. It appears that SNS is useful for evacuating people to exits promptly during emergencies. The manner in which SNS serves as a powerful tool is exemplified as an example of the framework's validation process.

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