On Usefulness and Reliability of MAS for Mass Evacuation Analysis

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Multi agent analysis (MAS) is being used for mass evacuation analysis, since it is applicable to problems of complicated setting. For a better use of MAS, this paper discusses the usefulness and reliability of MAS, in view of its objective of smoothening evacuation processes. First, the requirements of MAS are discussed. Some requirements are clarified for two elements of MAS, environment and agent. The usefulness is then discussed, picking up analysis of the current state, estimating measures taken for smoothen evacuation processes, and disaster education. The reliability is discussed in terms of verification and validation of MAS as a numerical analysis method. Pointed out is importance of verification for agent-wise behavior and validation for overall behavior.

Key Words : *mass evacuation analysis, multi agent simulation, verification and validation*

1. INTRODUCTION

Mass evacuation analysis is a relatively new topic in earthquake engineering, compared with seismic structure response analysis used in seismic resistance design. Its importance is well recognized in view of human casualties in 2011 Tohoku Earthquake which accompanies tsunami of largest class. While various numerical methods are used for the mass evacuation analysis, multi agent simulation (MAS) is a promising method[1,2,3)] since it is able to take full advantage of recent computer science and technology. MAS for mass evacuation analysis is able to solve problems of quite complicated setting, to which other numerical methods are not applicable; for instance, see Appendix. As for the scalability of MAS, parallel computation is used for it.

The objective of the mass evacuation analysis in case of an earthquake or a tsunami is simple. That is, realization of smoothening evacuation processes, just like the seismic structure response analysis which is used in order to make rational seismic resistance design. It is not an objective, at least a primary one, to reproduce or predict a panic situation during the evacuation processes.

While the objective of the mass evacuation analysis is well-defined, its realization is not straightforward because feasible measures to smoothen evacuation processes are limited. Even if the most reliable MAS is used to analyze mass evacuation processes, it is not useful to smoothen the mass evacuation. It is surely desirable to make MAS more reliable simulation. However, the usefulness of the mass evacuation simulation should be linked to its objective.

In this paper, we discuss the usefulness and reliability of MAS for the mass evacuation analysis during an earthquake or a tsunami. We do not intend to draw exclusive conclusions from this discussion. We wish to clarify requirements of MAS to achieve its objective and to identify possible directions of developing better MAS for the mass evacuation analysis.

The contents of this paper are as follows. First, we summarize the requirements of MAS for the mass evacuation analysis. Next, we discuss its usefulness, paying an attention to the limitation of feasible measures taken for smoothening the evacuation processes. We then discuss the reliability of MAS for the mass evacuation analysis, showing methodologies of the verification and validation of MAS as a numerical analysis method. Some remarks are made in the end of this paper.

2. REQUIREMENTS OF MAS FOR MASS EVACUATION ANALYSIS

There are requirements for MAS to be used as a numerical method of mass evacuation analysis. Since MAS has two basic elements, namely, environment and agent, we summarize these requirements for each element. Note that the environment is a set of routes for evacuation, and the agent is a model of an individual who does evacuation.

(1) Requirements of environment

The first and essential requirement of the environment is that it must reflect an actual road network which includes streets, arrays and paths. It is thus desirable to automatically construct a model for the environment from available data such as Geographic Information System (GIS) of the road network. The configuration such as road width, which is used as an index of flow capacity of the road, should be included in the model.

It is certainly desirable if the environment is able to reflect damages induced on the road network by strong ground motion. While the damage is local, it could decrease the overall capacity of the road network. However, it is not trivial to quantitatively evaluate the effects of the damage on the capacity. A most simple and straightforward modeling is the reduction of the road width.

The environment needs to reflect measures which are implemented on the road network for smoothening evacuation processes; for instance, setting road signs is a standard measure, and the effect of the signs should be modeled in the environment. Again, quantifying this effect is not trivial at all. A simple modeling is to force agents smoothly move in the direction of the sign.

(2) Requirements of agent

In general, suitable modeling of agent is an essential requirement of MAS. However, no systematic methodology of modeling has been established. Since Object-oriented programing (OOP) is usually used, considering the code structure of MAS, which follows OOP, we clarify the requirements in modeling agent for each element of the code structure; agent is coded as an object, and this object consists of two element, data and functionality; see **Fig.1**.

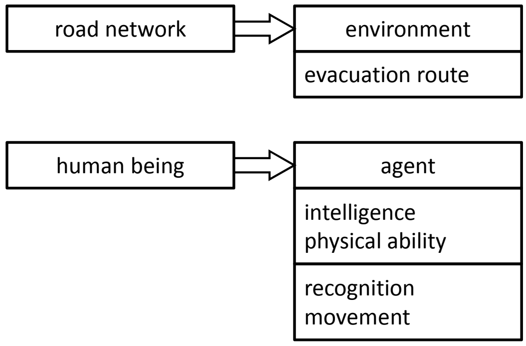

Fig.1 Two elements of MAS and its code structure.

It should be noted that, even though the code structure of MAS is common as it follows OOP, the code content changes for each code. A more sophisticated code has larger contents. In view of its objective, MAS for mass evacuation analysis does not have to have highest complexity in the code content. However, it is not acceptable to keep using the simplest content since the mass evacuation analysis is directly concerned with human casualty. Thus, the requirements of agent modeling must take a balance between the complexity and suppleness.

a) Data of agent

Since an agent is a model of human being, it must have data for intelligence and physical ability. Intelligence is related to the agent's understanding of the surrounding environment and agents. Cognition is of primary importance for MAS, since it is the first step to initiate environment-agent interaction and agent-agent interaction, which is related to the contents of MAS.

Physical ability is an agent's speed of moving in an environment. Visibility would be included in the physical ability. An agent has its own characteristic of the physical ability, so that diversity of mass evacuation processes can be simulated. It is desirable to use a distribution of human being walking/running speed at an emergency state, although no data is available and measuring such a distribution is difficult.

The agent's speed should not be constant, and vary depending on a situation which is determined by the near-by environment and other agents. An extreme case of such a situation is an agent using stairs or an agent put in a dense crowd. The complexity is increased if a more sophisticated treatment is made for varying an agent's speed. Thus, implanting functionality for varying speed is better than setting a database which relates the situation to the agent's speed.

b) Functionality of agent

Relating to the two basic data, intelligence and physical ability, we need at least two functionalities of agent. Namely, the two are a functionality of recognizing the surroundings and a functionality of moving in the environment.

In general, it is a challenging task to design a suitable functionality of recognizing the surroundings for MAS; as mentioned, cognition is of primary importance for MAS. Since MAS for mass evacuation is to compute the movement of agents, this functionality should have the following two specific targets: 1) the surrounding environment, which gives restriction to the direction of the agent's movement; and 2) nearby agents, for which the agent has to change its direction, to reduce its speed, or to stop to avoid collision.

The functionality of moving could be very simple, if the mechanism of agent-interaction such as collision, retention, stagnation or overtaking is not included. The complexity of this functionality increases if a more sophisticated model is implemented for these mechanisms.

A functionality of communication among agents should be included to make a realistic simulation. Agent-agent interaction via this functionality is a mechanism which enforces a group of agents, which do not start evacuation, to initiate evacuation; without this, an agent starts evacuation only by itself. A functionality of the environment to deliver hazard information to agent is also important, in order to enforce agents' movement, to make them decide their movement direction or terminals.

3. USEFULLNESS OF MAS FOR MASS EVACUATION ANALYSIS

In the present paper, we presume that the objective of the evacuation analysis in an earthquake or a tsunami is to smoothen evacuation processes. The usefulness of MAS is thus evaluated in terms of the contribution of MAS to achieve this objective. To achieve smoothen evacuation processes; we first identify bottlenecks of evacuation, if any, by analyzing the current state of mass evacuation. Then we evaluate effects which are made by implementing a certain measure(s) on resolving the bottlenecks.

(1) Analysis of current state of mass evacuation

An advantage of employing MAS as a numerical method of mass evacuation analysis is that it is able to make more sophisticated analysis of the state of mass evacuation for current road networks and residents, compared with other methods. This is because MAS is aimed at mimicing human being and its community. We have to emphasize that MAS has an advantage does not mean that the output of MAS is the best. It is the level of modeling that determines the quality of the output.

In MAS, it is easy to find a bottleneck(s) in a particular part of the road network where agent movement is hinged. There are several mechanisms which cause the bottleneck and implementing the mechanisms into MAS is difficult. Hence, the bottleneck found in MAS is not always correct. However, if the same part tends to be a bottleneck in a Monte Carlo simulation which changes initial conditions (such as location) of agents, we may regard that part as the true bottleneck in the road network.

Preparation to initiate evacuation is another bottleneck in mass evacuation. In reality, there are many residents in coastal areas who heisted to start evacuation right after a big earthquake. Casualty of tsunami is due to this preparation or hesitation to start evacuation. However, identifying this bottleneck quantitatively is much more difficult than finding a bottleneck in a road network.

(2) Evaluation of implementing measures

The number of measures which are actually implemented for smoothening evacuation processes is limited. Moreover, it is difficult to quantitatively evaluate their effectiveness. MAS for mass evacuation analysis is used to evaluate the improvement of mass evacuation processes, by comparing a case when the measure is implemented with the one case when it is not implemented; this comparison is similar to "with/without of a new policy." As an index, the time in which all agents finish evacuation, called total evacuation time, could be used for the comparison of the two cases.

We should emphasize the total evacuation time depends on the initial conditions of agents. A Monte Calro simulation produces a statistica distribution of this index. Hence, the comparison should be made in a statistical manner, by using the average and variance of the total evacuation time.

As far as the authors have studied, there are some researches which examine effects of measures on smoothening evacuation using a mass evacuation analysis. We briefly explain them as an example of evaluating measures, as well as candidates of measures which can be evaluated by using MAS.

a) Warning information delivery

An example of such examined measures is delivering warning to initiate evacuation to residents. Delivering warning surely reduces the total evacuation time, although it does not reduce the time sufficiently for the entire resident to safely evacuate.

An actual measure of delivering information is to use a broadcasting system. All or some agents are forced to start evacuation. Another actual measure is to use an automobile which runs in an environment, delivering warning information to near-by agents.

b) Introduction of official agent

Official agent enforces other agents which does not initiate evacuation to do so. Introduction of such official agent in MAS is another measure of smoothening evacuation processes.

This agent models a policeman, a firefighter, or a community leader. Such individuals who have responsibility of disaster mitigation could be a precious human resource with which an effective measure of smoothening evacuation processes is implemented.

c) Use of automobile

A measure which should be examined is the use of automobiles. In general, walking is recommended for evacuation; if many people use automobiles for evacuation, it surely results in causing traffic jams. Depending on the population density, however, using an automobile might be a rational choice, especially for those who need assistance in moving.

MAS for evacuation analysis is able to provide a solution about an acceptable amount of residents who use automobiles instead of walking. We should point out that MAS is a unique tool which can provide such a solution, considering positive and negative effects of using automobile for evacuation. Note that the reliability of the MAS solution is a different issue.

(3) Disaster education

We cannot underestimate the significance of disaster education as a measure of smoothening evacuation. In particular, early or spontaneous evacuation of an individual is essential for the case of tsunami. MAS for mass evacuation analysis could be used as a material of simulation based disaster education. There are numerous experiences, preserved in the form of photo or video clip, but they are the experience of the past and at the other places for the majority. It is surely more appearing if MAS is made for a target area, even though MAS is virtual.

Strong ground motion induces damages on a road network; road itself is damaged, and, moreover, full or partial collapse of near-by structures causes mal functioning. Such damage hinges smooth evacuation. If MAS for mass evacuation analysis demonstrates negative effects of the structure damages on mass evacuation, residents will be aware of another impotence of retrofitting their houses and buildings, as it reduces a possibility of the road network malfunctioning. In this viewpoint, it is essential for MAS to implement structure damage influences on the environment in it.

While it is aimed at smoothening evacuation, disaster education using MAS for mass evacuation analysis also contributes to form a common recognition of possible earthquake disasters, which range from damage of structures to malfunctioning of road networks. At this moment, it is certainly difficult to draw a correct overview of the possible earthquake disasters. However, we should not stop improving our technology in capturing the disasters, by developing a new technology such as MAS; see Appendix B for a candidate of the new technology that uses MAS.

4. RELIABIILTY OF MAS FOR MASS EVACUATION ANALYSIS

In general, verification and validation are indispensable for a numerical analysis method. Here, verification means that the method is able to calculate a correct answer for a well-posed problem, and validation means that output of the method satisfactorily matches reality which is actually observed.

We should point out that, compared with a numerical analysis method such as finite element method (FEM), it is much more difficult to verify and validate MAS. This is because it is aimed at dealing with human behavior which does not have well established mathematical model. **Table 1** summarizes the comparison of FEM and MAS in terms of verification and validation.

(1) Problem setting

A suitable problem setting is essential to carry out verification or validation in an objective manner. Since OOP is used for MAS, the setting is concerned for its two elements, environment and agent. The problem setting of the environment is related to the requirements. Since the environment is a model of a target road network, the setting is mainly concerned about the configuration and capacity of the network. Qualitative description is needed in setting the environment.

It is surely acceptable that the degree of sophisticatedness in setting the environment changes depending on each code of MAS. This is because no methodology is established in modeling the road network. However, we should qualitatively clarify the degree of sophistications, to compare the results of other MAS's .

(2) Verification of MAS

It is straightforward to compute evacuation time if an individual's walking (running) speed and a distance to his/her terminal are given. Difficulty arises when he/she does not move smoothly. As the fundamentals, MAS for mass evacuation analysis must satisfy the following two properties: 1) an agent moves smoothly under an ordinary situation; and 2) some mechanisms are included which prevent smooth moving.

The verification of the first property is easy. For

Table 1 Comparison of FEM and MAS in terms of verification and validation.

	FEM	MAS
problem	initial-boundary-value problem, which is well posed in terms of mathematics	movement of agents in environment, which is not explicitly posed in terms of mathematics
verification	comparison of displacement, strain, or stress field with analytical solution	check of agent-wise behavior, such as agent movement under several situations
validation	comparison of point-wise measured displacement or force with experimental or observed data	check of overall behavior of agents, such as total evacuation time in which all agents complete evacuation

simplicity, we can check an agent movement when it is put in an environment that corresponds to a straight street. It is worth being examined the agent's movement for a curved or cranked road. A trajectory of the agent may be used to verify the functionality of moving.

It is the second property that needs special condition for the verification; a specific verification may be made for each mechanism which prevents smooth moving. The simplest mechanism is the reduction of agents' speed due as the spatial density of the agent is increased. Some observed data are available for the relation between the walking speed and the density.

For other mechanism, observed data which can be used for the verification are not available or limited. Thus, as mentioned, a specific verification might be required. For instance, the mechanism of overtaking is verified by checking the trajectory of two (or more) agents. While it sounds contradictory, we may make qualitative verification.

(3) Validation of MAS

In general, validation is more difficult than verification for a numerical method; verification is to check the method solves correctly, while validation is to check a problem solved actually corresponds to a reality. Unlike a numerical method of solving mathematics-physics problem, MAS is aimed at studying a social issue for which a mathematical problem is not posed well. Hence, validation of MAS is much more difficult.

In view of the objective of MAS for mass evacuation, what should be validated needs to be discussed. It is surely impossible to perfectly reproduce or predict a time history of an individual's evacuation process. Instead of individual movement, validation of MAS is aimed at overall processes of resident community or a group of individuals who belong to a certain organization. The evacuation time could be a good index which is used for the verification.

The variability in human behavior should not be underestimated, since it is strongly related to the human nature. Even if the overall processes are chosen as a target of validation, we have to consider their variability. As for the evacuation time, it varies depending on various factors; or it cannot be reproducible even if the same group of people evacuate under the same condition.

Although limited, some observed data are available for the overall behavior of residents evacuating from an area hit by an earthquake. Such data can be used for the validation of MAS. We should emphasize that the validation should be made by using these data, with paying due consideration to the variability of the overall behavior.

5. CONCLUDING REMARKS

As far as the authors have studied, this paper is the first attempt to discuss the usefulness and reliability of MAS for mass evacuation; similar attempts have been made for MAS of other purposes or for mass evacuation analysis from fire. Thus, more discussions and studies are needed to draw conclusions on the usefulness and reliability.

The procedures of discussing the usefulness and reliability of MAS for mass evacuation analysis might be worth being mentioned, since, we believe, they are systematic. Clarifying the requirements, we discuss the usefulness in view of the objective of the analysis. The reliability is examined in terms of verification and validation; at this moment, verification is made for agent-wise behavior, and validation is made for overall behavior.

APPENDIX A. SCALABILITY OF MAS

When it is applied to a large urban area, MAS for mass evacuation analysis needs to take advantage of high performance computing[4)] which uses parallel computing. Evacuation processes of millions of people could be a good problem for MAS to analyze, and more realistic problem setting would be requested. Both contribute the increase in the size of the problem which MAS must solve.

Scalability of MAS in parallel computation is generally low, since agent-agent interaction increases more than linear to the number of agents. Highest numerical techniques should be implemented in a code of MAS. New techniques which are specially designed for MAS need to be developed as well.

APPENDIX B. OPTIMIZATION OF MASS EVACUATION PROCESSES

As mentioned several times, the primary objective of MAS for mass evacuation analysis is to smoothen evacuation processes. It is regarded as an optimization problem, by shortening the evacuation time. If each individual location is monitored, it is able to find an optimal route for him/her, by analyzing the movement of him/her together with the surrounding individuals.

Continuous monitoring of individual locations is possible by using a smart phone. It is also possible to keep sending each individual some information about where to go using such a communication device. While it is a big task to keep gathering all data of the locations, MAS can be used as a numerical analysis method which analyzes these data to find optimal routes for all individuals. This link of monitoring and MAS will optimize the mass evacuation process.

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