Multiagent Based Tsunami Evacuation Simulation: A Conceptual Model

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Abstract. During emergency situation, such as a large-scale tsunami or other disastrous events, people evacuation may lead to more fatalities when it is conducted without a proper escape strategy. The ability to evacuate a huge number of people within a very limited amount of time is certainly required. Evacuation drills are therefore necessary to acquire an optimal escape strategy. Unfortunately, we have to deal with both financial and practical challenges for conducting a regular and meaningful drill. To overcome these challenges, one solution would be to develop the evacuation simulation model. Despite its limitation to mimic the real-life situations, simulation may provide practical ways of minimizing the negative consequences as well as useful insights to escape strategy. In this paper, we describe a conceptual model of multiagent based tsunami evacuation simulation (TES). The model formulation and description would follow the ODD (Overview, Design concepts, and Details) protocol, which is a standard protocol widely used by agent-based modellers. The proposed model may serve as a framework for TES that offers the following features: estimate the clearing time or the time needed by people to leave the tsunami inundation area, and identify the potential bottleneck or congestion locations. Using the proposed conceptual model, we consider constructing the TES for Calang district, a coastal area in Aceh Jaya regency, for future work.
Keywords: multiagent modeling, agent based modelling, evacuation simulation, tsunami.

Introduction

Emergency evacuation can be simply defined as the urgent movement of people from a threatening place or situation due to occurrence of a disastrous event (Ren, 2009). The aim of evacuation is primarily at saving the life of people. When it is improperly carried out, evacuation may lead to more facilities. Therefore, during evacuation, the ability to move a huge number of people within a very limited time is required.

Imamura *et al*. (2009) identified three steps that lead to a safe evacuation after an earthquake and tsunami: collect information and issue an official warning; make a decision to evacuate based on risk perception and past experiences of the people in the area; and choose a proper route and safe destination for the evacuees. Focusing on the last point, one way to provide people with knowledge on safe route and destination is by conducting regular evacuation drills. However, the drill is expensive to be carried out and it is difficult to enable many residents to take part (Goto, 2012).

To overcome both financial and practical challenges, one solution would be to develop the evacuation simulation model. Despite its limitation to mimic the real-life situations, simulation may offer useful insights to escape strategy and provide practical ways of minimizing the negative consequences as well. Previous efforts have been demonstrated the effectiveness of the evacuation simulation (Yozo Goto, 2012; Mas, 2012). Both of the works relied on multiagent approach. Goto (2012) stressed the use of evacuation simulation for disaster education and city planning in Banda Aceh area. Whereas Mas et.al (2012) integrate tsunami and evacuation modelling for the case of 2011 great east Japan tsunami in Arahama, Sendai City, Japan. The simulation outputs include the estimated number of survivors and casualties. Although based on multiagent, the model formulation and description of the previous works did not follow the ODD (Overview, Design concepts, and Details) protocol, which is a standard protocol widely used by agent-based modellers (Railsback, 2012).

In this paper, we will describe a conceptual model of multiagent based tsunami evacuation simulation (TES). The model is formulated and described using the ODD protocol. We focus on various scenarios that estimate the clearing time (the time needed by people to leave the area) and the associated potential congestion points.

Materials and Methods

In general, the conceptual model is developed following the below steps.

- An intensive literature review related to emergency events, multi-agent based simulation, crowd behaviour and crowd modelling.
- Identification of user requirements.
- Design process that relies on the user requirements. Technical description of TES is formulated using the ODD protocol.
- Development of the conceptual model and application prototype.

According to Goto (2012), the movement of people in evacuation is a kind of crowd flow simulations and can be implemented using multiagents. We adopt the same approach, in which individual agents are modelled to move along a digitized road network map based on predefined rules.

The following rules are considered (Goto, 2012): agents must follow road network data links from their houses to evacuation sites following the shortest possible path in terms of physical length for walking and motorcycle; if the road is wide enough, faster agents pass slower ones.

Agent based modelling

Agent-based modelling (ABM) is a form of computational or computer simulation that extends the artificial intelligence ability. ABM is commonly used to model and simulate problems in engineering and social science. Modelling in social science is to get a simple model that can represent events or social reality as closely as possible with adequate level of trust to the real condition. The model is formulated into computer program where there are several inputs with independent variables and several outputs with dependent variables. The computer program will process the input to a real condition in the social world. One of the reality conditions in the social world is disaster emergency management especially in the disaster evacuation modelling (Ren, 2009). ABM is also defined as a model where individuals or agents are described as unique and autonomous entities that usually interact with each other and their environment locally. In ABM, agents are assumed different from each other; that they interact with only some, not all other agents; that they change over time; that they can have different life cycles or stages they progress through, possibly including birth and death; and that they make autonomous adaptive decisions to obtain their objectives.

ABM and simulation that called as ABMS is a combined model to show the interaction between agent and its environment independently. ABMS is very helpful for clarification, implementation, providing, and validation of a theory.

ABMS is also a powerful simulation modelling techniques for several applications in the business world problems (Ren, 2009). In the ABMS, a system is modelled as a set of autonomous decision-making entities well known agents. Each agent individually apperceives state of him and his environment, and interactions with other agents, and then makes a decision on the basis of a set of given rules. Advanced agent can even change their action rules as they gained experience.

The advantages of ABMS technique is flexible, capture phenomena emergency and provides natural description of a system (Ren, 2009). So the ABMS is an ideal application for a disaster emergency evacuation simulation because it provides valuable insight into the mechanisms of and preconditions for panic and jamming.

Walking and motorcycle evacuation

There are three types of walking people exposed in this simulation, young men or women who move faster than other two types like children and old people, and old people move slower than children. Every of these agents will walk based on their speed to find the available exits, the evacuation building or the higher place for example to avoid getting hit by tsunami. Recall the basic assumption, the simulation only uses one type of vehicular for evacuation that is motorcycle. All these agents in this simulation utilize the same wide of the street space while they evacuate.

Required data

To build a multiagent based TES, we identified at least two kinds of data, which is:

- Environment data, which related to the affected and safe area, such as:
  - Road network
  - Road width
  - Junction characteristic
  - Evacuation route, exit point and safe destinations
  - Area that hit by the tsunami
- Agent related data, that describe the characteristics of population, such as:
  - Mode of evacuation mode (pedestrian/walking evacuation, or using vehicles)
  - Moving speed, depend on the mode of evacuation
  - Time that needed by population to start evacuation
  - Population density
  - Age density

Model, ODD protocol, and prototype

A model can be defined as "a purposeful representation of some real system" (Starfield *et al.*, 1990, in Railsback, 2012). Since real systems are often too complex, models are developed and used to solve problems or answer questions related to the systems of interest (Railsback, 2012). A model could not be formulated without a firm understanding of how the system works. Furthermore, a proper model has to be built based on a systematic approach. Railsback *et al.* (2012) proposes the modelling cycle that consists of the following activities:

1. Formulate the question

The first task is to generate a specific research question. A focus and clear research question is necessary in building a representative model.

2. Assemble hypotheses for essential processes and structures

Based on the research question, a number of hypotheses are generated covering only the essential processes and structures.

3. Choose scales, entities, state variables, processes, and parameters

After choosing several simplifying assumptions and hypotheses, a more details attributes of the system is formulated.

4. Implement the model

This activity translates the verbal model description into simulation object using mathematics and computer programs.

5. Analyse, test, and revise the model

After being implemented, the model should be analysed, tested and revised. It should be adapted to the new findings during testing activities.

In order to build a good model and we could gain more understanding from it, the above modelling cycle is iteratively carried out until the required conditions are satisfied.

The ODD protocol

In *agent based modelling*, one way to describe and formulate the model is using the ODD (Overview, Design concepts, and Details) protocol (Railsback, 2012). The ODD protocol enables us to reimplement the models and replicate their results. Tabel 1 describes the element of the ODD protocol (Railsback, 2012). The protocol consists of seven elements. The first three elements provide an overview, the fourth one describes general concepts underlying the model's design, and the remaining three elements explain details.

In the following part, the model formulation based on the ODD protocol will be presented.

Table 1. The seven elements of ODD protocol.

Elements of the ODD protocol	
Overview	1. Purpose 2. Entities, state variables, and scales 3. Process overview and scheduling
Design Concepts	4. Design concepts • Basic principles • Emergence • Adaptation • Objectives • Learning • Prediction • Sensing • Interaction • Stochasticity • Collectives • Observation
Details	5. Initialization 6. Input data 7. Sub models

1. Purpose

The purpose of TES model is to explore the dynamics of people, evacuation scenarios and their consequences during tsunami evacuation. The main questions addressed are: what is the clearing time or the time needed by people to leave the tsunami inundation area? Are there any potential bottleneck or congestion locations?

2. Entities, state variables, and scales

Three types of agents are considered in this model, representing the simple evacuee's mobility and behaviours.

a. Agent that evacuate using motorcycle, this type of agent consist 2-3 persons for each motorcycles/agent.
b. Agent that evacuate on foot with normal speed, this type of agent usually a young and healthy pedestrian.
c. Agent that evacuate on foot with slow speed, this type of agent are kids, old peoples, or sick peoples. The characteristic of each agent is described Table 2.

Table 2. Type and characteristic of agents

Type	Evacuation Method	Speed (average)	Time to Start Evacuate
1	By Motorcycles	30 Km/hours	100 seconds after the earthquake
2	On Foot (Normal Speed)	5,5 Km/hours	Immediately
3	On Foot (Slow Speed)	2,7 Km/hours	Immediately

The agents crowd is assumed to be ideal with 1 agent/m^2. Their mobility condition is either moving or completely stop. The agents move following the city street, with 6 meters width, until they reach their goal point.

3. Process overview and scheduling

The evacuation process is started when there is a warning of the potential tsunami. This can be a strong earthquake, sirine from the early warning system, or an evacuation message from people or authorities. The transmission mechanism of the warning message is not considered. The following process is performed:

1. Determine number of agents that represents the population in the area.
2. Agents are grouped according to their characteristics in Table 2.
3. Determine the evacuation points. This could be hills, evacuation building, etc.
4. Determine the evacuation routes and their links to the evacuation points.

5. Agents will move to the specified evacuation points.
6. Records the congested points.

4. Design Concept

The *basic principle* addressed by the TES is the movement of the agents (that represent people) to the designated evacuation points. Agent randomly moves along a digitized road network map based on predefined rules. At each scenario, the model will *emerge* two variables, the clearing time or the time needed by people to leave the affected area, and the congestion points. One of the *adaptive behaviour* is represented by the agent's ability to choose the shortest destination.

The *objective* and *prediction* are not explicitly considered, and there is no *learning* in the model. *Sensing* is important, agents are assumed able to identify the shortest distance of the exit point and follow the digitized road network map. The model includes only simple *interactions* between agents; family members tend to move collectively. The *stochastic* process is used to initialize agent movements and their direction. However, empirically determined probabilities are not considered. *The* collective aspect is used to determined congestion in certain points. A huge number of agents in a location served as an indicator of congestion or bottleneck. To allow o*bservation* of clearing time and congestion points, the time and number of agents are recorded.

5. Initialization

A digitized road network of the area is initialized when model starts, including the number and location of the evacuation areas.

6. Input Data

The tsunami affected area and the evacuation points are assumed to be constant, so the model has no input data.

7. Sub Models

There are no sub models for this TES model.

Prototype

Considering the previously described ODD protocol, we are implementing the conceptual model of TES using NetMAS, a multiagent software tool. We choose the area of Calang City, in Aceh Jaya district of Aceh Province, which is a high tsunami risk region. The considered area is 4 Km x 2 Km, or 8 Km^2, with a population of 7.683 people. The satellite image of Calang City is givin in Figure 1.

Figure 1. Satellite image of Calang city.

As shown in Figure 2, the prototype has two mode. The first one is editor mode, where coding and parameters of simulation is inputted. The second is simulation mode, in which the simulation and the result are presented. As of this writing, the prototype is still under development. Hence, results and analysis are left for future works.

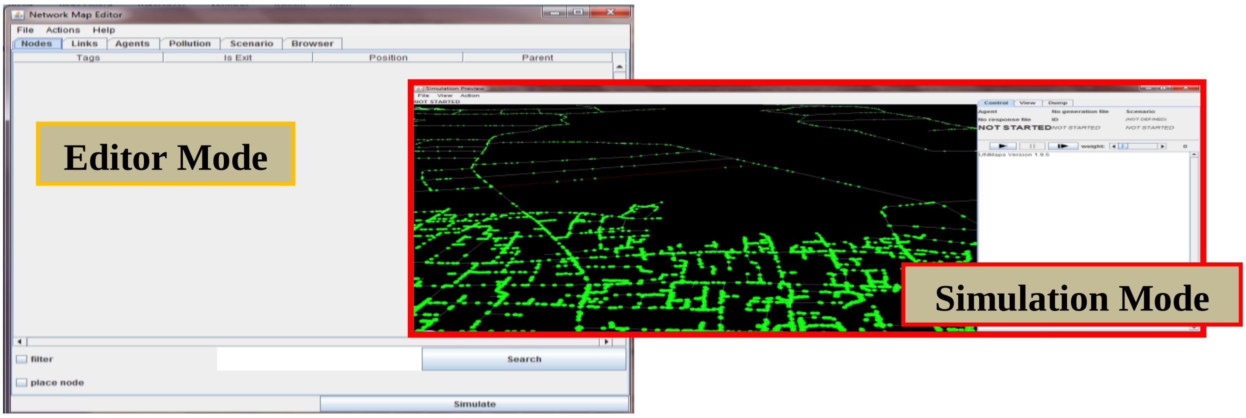

Figure 2. Screenshots of tsunami evacuation simulation.

Conclusions

This paper described a conceptual model of multiagent based tsunami evacuation simulation. The model is formulated using the ODD (Overview, Design concepts, and Details) protocol, which is a standard protocol widely used by agent-based modellers. The required data for the model, i.e., the environment and agent related data, is also identified. The proposed model offers two main outputs: the estimated clearing time at the affected area and potential congestion points.

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