

A Simulation System for Tsunami Evacuation Behavior in the JR Osaka Station Area

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Abstract— In response to an estimation of the likelihood of occurrence of the Tonankai and Nankai earthquakes, it is predicted that tsunami damage will occur in the JR Osaka Station area, the third biggest business center in Japan. The purpose of this study is to propose a system that evaluates the effectiveness of tsunami evacuation guidance and tsunami countermeasures, based on computer simulation of behavior of evacuees. There are many companies, department stores, hotels, large underground shopping centers and railway/subway stations in this area. Various kinds of elements must be considered in order to plan safe evacuation. For example, there must be major disruptions between people who try to evacuate from buildings and people who try to get out of the underground shopping center and buildings. In this paper, the first step of the study is reported, that is an evacuation simulator to collect data fundamental for devising a method for inducing evacuation.

Keywords—Tsunami; earthquake; simulation; multi-agent system; Osaka City; evacuation.

I. INTRODUCTION

Earthquakes occur so often in Japan that it is particularly well known as an earthquake-prone country. At present, there are four major earthquakes predicted to occur in Japan in the near future: the Tokai earthquake, the Tonankai earthquake, the Nankai earthquake, and the Tokyo Metropolitan earthquake. In particular, the probability of occurrence of the Tokai earthquake in the next 30 years is estimated to be 87%, and those of the Tonankai and Tokai earthquakes are also estimated to be greater than 60% [1]. If these earthquakes actually occur, there must be massive damage and many stranded people unable to return home.

In the Tohoku Great Earthquake in 2011, there was a major disruption by over 5 million stranded people in Tokyo and the surrounding areas. The same situation is predicted in Osaka City, the second largest city in Japan, which would be greatly affected by the Nankai and Tonakai earthquake. JR Osaka Station, Midosuji (a main street in the city), Osaka City Hall, etc., are located in Osaka City. These are specified as being within the predicted tsunami flood region, and it has been predicted that massive damage to the municipal subways and underground shopping centers will occur. There are many people, particularly tourists, shoppers and

commuters, in the area of JR Osaka Station, and there is the possibility of about 420,000 people being trapped; widespread confusion may occur as they take refuge from a tsunami during an earthquake disaster [2]. In addition, secondary and tertiary disasters may result from the original disaster. They are the disasters that occur subsequent to when a disaster occurs. Therefore, there is a need to conduct quick and precise evacuation guidance in the context of reviewing prevention measures to reduce major damage in Osaka City. Evacuation simulation by computer is thought to be effective because it is difficult to conduct an experiment of evacuation guidance on a real-life scale in the JR Osaka Station area, which may result in major traffic congestion and disruption.

In order to solve these problems, this research aims to construct a working environment that can evaluate the evacuation guidance and tsunami countermeasures by simulating the behavior of disaster victims on a computer, targeting JR Osaka Station and its surrounding areas.

II. RELATED WORK

A. Evacuation Simulation: State of the Art

Various research and development of crowd evacuation behavior simulations have been conducted in relation to fire and tsunami situations [3][4]. In order to develop a method for predicting evacuation behavior that incorporates panic conditions, we will examine the state of the art in terms of numerical analysis methods.

1) Physical Model Method

The physical model method [3] assumes that a crowd will take action following specific physical laws.

This commonly used method regards crowds as fluid, and calculates the number of people per speed and space by design of the line of flow in buildings, which is called the fluid model. In cases when the crowd acts smoothly, this method is effective and highly reliable. It is capable of simulating situations where the flow of people is blocked, by setting the proper parameters using calculation, but it is also necessary to set parameters considering the structure of buildings.

An individual member of the crowd is regarded as a single rigid body, and the grains model [3] has been used to

model their movement in situations where they move while interacting with each other. Compared with the fluid model, this is capable of expressing detailed movement, but the calculation costs higher.

Over the past few years, several studies have been conducted on simulation models using the potential model as a highly physical model [3]. It is possible to simulate various evacuation behaviors including blockades by setting appropriate potential to the spatial properties of route, individuality of evacuees, and the disaster situation, etc., but the reliability of results depends on the quality of the set potential. It is capable of simulating situations, but there are no principles or methods of determining potential objectively, so it is not suitable for predicting emergency evacuation behavior, where ensuring reliability is important.

2) Cellular Automaton Method

The cellular automaton method [3] is used to calculate the movement of crowds as a state transition between cells, following a simple rule using probability by dealing with time and space discretely. Although the rule is simple, it is possible to form a complex transition pattern by splitting time and space among a large number of cells. In the case of evacuation behavior, if state transition between cells is modeled as the ensemble behavior of each pedestrian, it is possible to implement various patterns of behavior by including or ignoring various elements of the determined behavioral rules of each evacuee. As a consequence, it is capable of reproducing complex state transition. The degree of freedom in setting the form of walking space and positioning facilities is high, and it is possible to easily program and to calculate complex boundary conditions, such as smoothly flowing evacuation patterns and blocked evacuation patterns.

This method is suitable for classifying qualitative patterns of state transition, but the quantitative prediction is limited. It is capable of predicting quantitatively by increasing the complexity of the rule, but this is not a strong point of this method.

3) Multi-agent Simulation

The multi-agent method “constructs a system bottom-up from the behavior of many autonomous agents” [4]. It regards individual elements constituting the system as agents, makes them act autonomously and simulates the behavior of the system. This method is sometimes described as an advanced type of the cellular automaton method, but it is notable for modeling decision-making and actions of individual evacuees, and has been practiced in the field of artificial intelligence since the late 1980s.

At present, it is possible to obtain reliable results through designing suitable agents, and various kinds of multi-agent simulation have been researched. For example, multi-agent simulations of evacuation behavior in fire emergencies have been developed, and it is planned to diversify to other disaster situations. In social technology, multi-agent simulations of risk management in nuclear power plants have been developed. For earthquake disasters, multi-agent

simulations have also been used to predict fire suppression and the actions of the police, etc.

B. Related Research

Various research and development of crowd evacuation behavior simulations have been conducted in relation to fire and tsunami situations. For example, Hori et al. conducted evacuation behavior simulations in underground spaces [3]. They experimented with multi-agent simulation on evacuation behavior from a subway station with five underground levels to the ground during an earthquake. Consequently, they were able to analyze evaluation findings such that the evacuation time of individual evacuees is uneven and increases according to the number of people.

In addition, Watanabe et al. developed an evacuation simulation model for tsunami situations using multi-agent simulation. During planning of community development of disaster prevention for tsunami situations, this research can examine both maintenance of material aspects and policy [5]; for instance, questions such as what kind of maintenance will enable all evacuees to escape within a set period of time.

III. OUTLINE OF PROPOSED SYSTEM

A. Current Problems

Until now, many studies have been made on simulations of human behavior using computers [6], [7]. In a conventional simulator, the principal purpose is to model the actions of evacuees simply as fluid and to simulate this movement, but simulators of not only physical interaction among evacuees but also social interaction have been developed recently. Fundamental questions still remain unanswered. As mentioned in Section II, there have been many simulations such as those targeting the damaged region, those conducted in internal spaces such as tower buildings, department stores, underground shopping centers, etc.; but there are not many simulators that model evacuation in metropolises such as Tokyo and Osaka, in which there are many large buildings and various groups of people. In addition, large-scale and large-area simulations of evacuation behavior which consider evacuee inflow to buildings do not exist. For this reason, it is not possible to predict what situations will occur in Osaka City during an earthquake in terms of collisions between people who try to evacuate to buildings and people who try to get out of the underground shopping center and buildings.

Furthermore, there is an immediate need to reconsider planning of disaster prevention related to the Nankai earthquake affecting Osaka City in the wake of the 2011 Tohoku Great Earthquake and Tsunami. In particular, measures in relation to tsunami resulting from an earthquake are a main object to be reconsidered. As the Yodo River is located close to JR Osaka Station and Hankyu Umeda station, it is predicted that widespread damage and confusion will occur in the event of a tsunami. In order to reduce such a damage, it is necessary to consider effective tsunami countermeasures. Currently, quick and precise evacuation guidance within the limited time period before a tsunami occurs is effective.

However, private companies and Osaka City administration do not share a specific control strategy for tsunami occurrence. For this reason, it can be assumed that firstly, the information needed to formulate a tsunami evacuation manual is lacking, and secondly, even if such information exists, it is not shared. As a result, individual company or institution is making a separate guidance manual for evacuation. In the case of actually basing evacuation guidance on such manuals, it is not clear whether these constitute effective guidance for a particular region. For instance, even if tsunami refuge buildings are capable of accommodating stranded people, they have a psychological resistance to moving higher than the third floor in buildings when elevators and escalators make emergency stops after an earthquake. In consequence, widespread confusion may occur in the case of many people remaining on lower floors while further evacuees enter the building. The same collision may occur on both the ground and underground levels. In order to resolve such problems, it is necessary to make a system that is capable of inspecting how evacuees will behave considering various evacuation situations.

B. Proposed System

The purpose of this study is to develop a computing system that simulates evacuation behavior of people at the time of tsunami precaution in major cities, including in the ground and the underground, and buildings. Furthermore, it is our goal to provide fundamental data for specifying tsunami refuge buildings and selecting the evacuation guidance method and system, the guiding location, etc. This paper is the first step in this objective, and thus we have developed a simulator of evacuation behavior which targets people located only on the ground level. Using this, we conducted a simulation targeting the area around JR Osaka Station and Umeda Station in various situations.

The following functions are considered in the system.

1) Functions

a) *Target area*: The target area is defined as the area within a kilometer radius of JR Osaka Station.

b) *Evacuation route*: The evacuation route used by evacuees is the shortest distance on the road network to JR Osaka Station. Further, it assumes that there are no obstacles such as cars on the road. In this research, we used Dijkstra's algorithm [8] to measure the fastest time to finish taking refuge, and it is set so that the evacuees do not take any detours even if the walking speed decreases due to dense crowding. We plan to consider the influence of road traffic and some disaster's psychological reaction in future research.

c) *Walking speed*: The speed used as a standard is considered to be 66.6m/min per one person/square meter from the relationship between crowd density and speed of the evacuees on the evacuation route. It is set so that the speed decreases as the congestion of people increases.

d) *Tsunami refuge buildings*: In order for evacuees to take refuge in places other than the goal, buildings in which

large numbers of evacuees, such as Umeda Station, department stores, and tower buildings etc. are designated. As such, buildings specified as tsunami refuge buildings are designated as buildings for emergency evacuation.

e) *Evacuee limit*: A control panel can be created so that the number of evacuees who can be accommodated in those buildings can be adjusted, and it can be set up with various values.

f) *Graphical representation*: The X-axis indicates lapsed time and the Y-axis shows the number of evacuees who have taken refuge in each building on the time series graph of the evacuee number.

IV. SYSTEM ARCHITECTURE

A. Development Environment

This research implements "artisoc 3.0", a multi-agent simulator developed by KOZO KEIKAKU ENGINEERING Inc. The rule description language is mainly Microsoft's Visual Basic. Artisoc 3.0 can graphically capture the motion of agents with numeric output, a 2D map and a 3D map.

The program construction of artisoc is a stepwise structure, as shown in Figure 1.



Figure 1. Artisoc program structure

B. Simulation Flow

The simulation flow of this system appears in Figure 2. Each step is explained below.

1) The evacuation route calculation agent calculates the shortest route to the goal using Dijkstra's algorithm and saves the data file.

2) The evacuee agents located at each intersection take the shortest route from each position to the goal based on this data. When all evacuees have finished taking the route, they are indicated on the map of the intersections by a green circle.

3) As shown in Figure 3, we set the evacuee limit for each emergency refuge building using a control panel. The slide bar is capable of adjusting the number of evacuees by units of 100 persons.

4) The evacuees start to take refuge at the goal. This simulation continues to run until all evacuees finish their journey, and it automatically finishes when all have completed refuge.

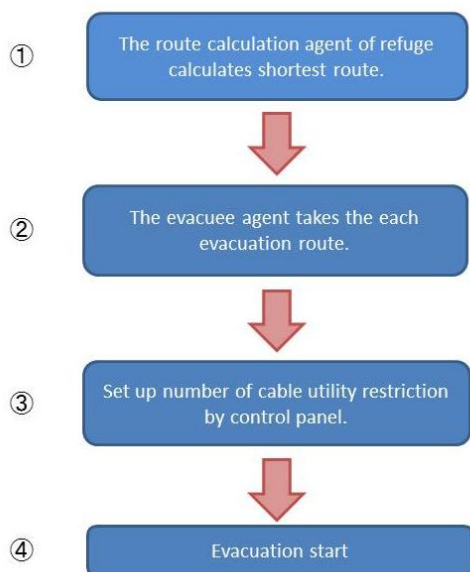


Figure 2. Simulation flow

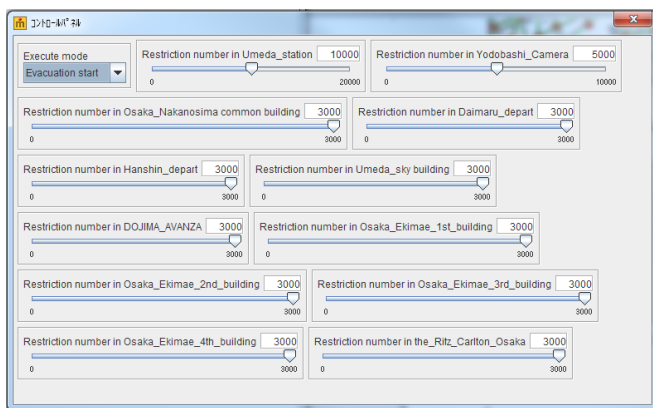


Figure 3. Control panel

C. Evacuee Behavior during Simulation

When we execute this simulation, the evacuee agent is displayed with a green circle and positioned at each intersection. Each green circle represents a group of 100 evacuees. In this experiment, this system only simulated the behavior of evacuees on the ground, so their numbers were set at approximately 200,000 persons.

In addition to this, this simulation assumed a situation where all evacuees would go to JR Osaka Station when an earthquake occurs. Therefore, JR Osaka Station is designated as the goal, which forms the basis of their behavior. The evacuation routes are shown in Figure 4, where green lines indicate roads, and the evacuees walk to the goal by the shortest route as calculated by Dijkstra’s algorithm. In

addition, as shown in Figure 5, when evacuees find emergency refuge buildings within 3 units around them, they do not go to JR Osaka Station but take refuge in these emergency buildings. However, if the number of evacuees that can be accommodated in each of these buildings reaches the established limit, they cannot enter, and thus return to the route going toward JR Osaka Station.

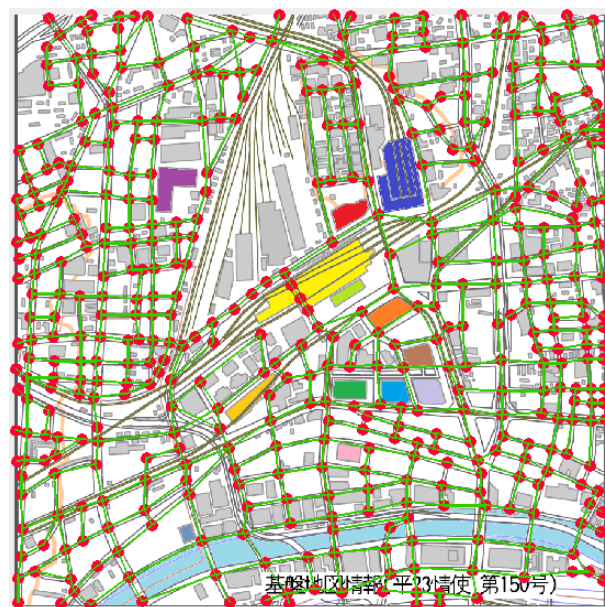


Figure 4. Evacuation routes and interactions

3	3	3	3	3	3	3
3	2	2	2	2	2	3
3	2	1	1	1	2	3
3	2	1	0	1	2	3
3	2	1	1	1	2	3
3	2	2	2	2	2	3
3	3	3	3	3	3	3

Figure 5. Range of evacuees’ view

In general, walking speed is said to be 66.6 meters per minute to population density of 1 person per square meter. However, each evacuee agent is assigned a group of 100 persons in this simulation, so it is predicted that their movement will be slow compared with typical walking speed. Accordingly, this was set to 40 meters per minute by considering such factors as the various physical constraints of group movement and the Fruin’s Level of Service [9], etc. Furthermore, we set the speed to fluctuate according to the congestion situation on the evacuation routes. Table 1 summarizes the numerical values of these fluctuations.

TABLE 1. WALKING SPEED

	Congestion factor		
	0-2	3-4	5-

Speed[m/min]	40	30	20
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D. Designation of tsunami refuge buildings

In this simulation, the evacuees take refuge not only at JR Osaka Station but also in surrounding buildings. As shown in Figure 3, a control panel can be created so that the number of evacuees that can be accommodated in those buildings can be adjusted, and it can be set up with various values. Table 2 summarizes the names of the tsunami refuge buildings and the number of evacuees that can be accommodated within.

TABLE 2. BUILDING NAMES AND ACCOMMODATED NUMBER OF PERSONS

	Color	Accommodated number(persons)
Umeda Station	Blue	0-20000
Yodobashi_Camera	Red	0-5000
Osaka_Nakanoshima common building	Grayish blue	0-3000
Daimaru_Department Store	Pea Green	0-3000
Hanshin_Department Store	Orange	0-3000
Umeda_Sky Building	Purple	0-3000
DOJIMA_AVANZA	Pink	0-4000
Osaka_Ekimae_1st_building	Green	0-4000
Osaka_Ekimae_2nd_building	Sky Blue	0-4000
Osaka_Ekimae_3rd_building	Light purple	0-4000
Osaka_Ekimae_4th_building	Brown	0-3000
Ritz_Carlton_Osaka	Bright yellow	0-2000

E. Execution Screen

The execution screen of this simulation is shown in Figure 6.

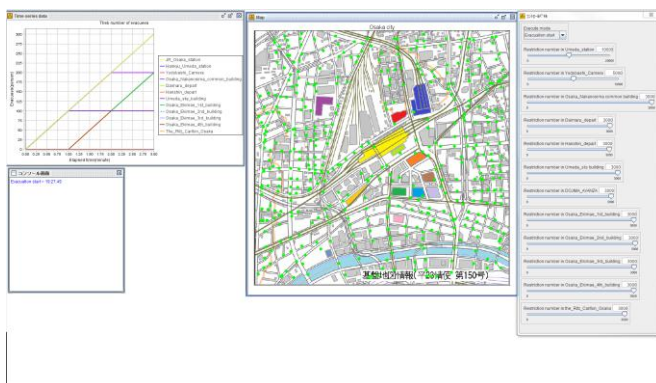


Figure 6. Execution Screen

V. RESULTS

A. Case Study

In this simulation, we can set the maximum possible number of accommodated evacuees in each emergency refuge building using a control panel. In this research, the simulation was conducted using various proportions of evacuees accommodated in the refuge buildings, as described in the conditions listed below.

- 1) When the proportion of evacuees who can be accommodated is 0%.
- 2) When the proportion of evacuees who can be accommodated is 20%.
- 3) When the proportion of evacuees who can be accommodated is 50%.
- 4) When the proportion of evacuees who can be accommodated is 80%.
- 5) When the proportion of evacuees who can be accommodated is 100%.

The data obtained by using the above proportions is shown in Figure 7. The transition of evacuees unable to find refuge each time is shown by a time series graph.

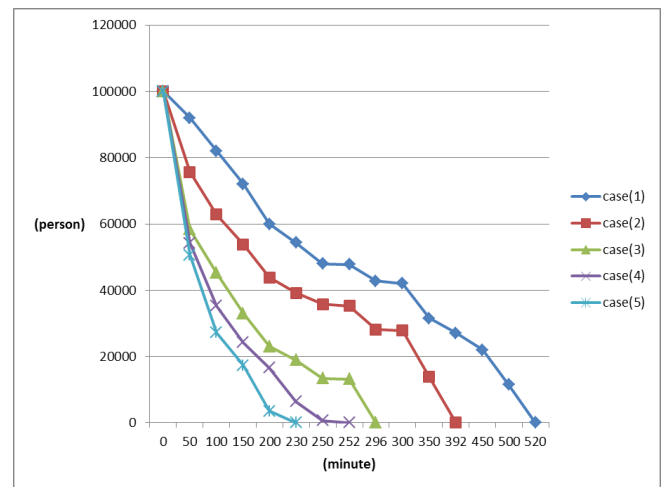


Figure 7. Transition of evacuees unable to find refuge

B. Discussion

In the case of Condition 1, Figure 7 shows that it takes a maximum time of 520 minutes until completion of refuge. Although evacuees go only to JR Osaka Station, it became apparent that it will take a considerable length of time for a group of 100,000 people to converge. Furthermore, the simulation result clearly shows that the time taken to complete refuge becomes shorter as the proportion of evacuees accommodated in the refuge buildings becomes higher. As a result, in this paper it can be concluded that designating tsunami refuge buildings such as stations, department stores, tower buildings, etc. enables evacuees to take refuge effectively and quickly in cases where they converge on one location.

However, the predicted time period for a tsunami to hit Osaka City is about 140 minutes after an earthquake, so the time calculated by the simulation exceeds the tsunami warning time, even with a crowd of 100,000 people. In this simulation, although there is the time lag before evacuees reach to JR Osaka Station, so many people actually aim at it. 100,000 people is said to be not few, but further more people have to be considered in the simulation.

Further, evacuees can cross the road in front of the station in this simulation, but it is predicted that the street will be clogged with traffic and they will be difficult to do so freely. Although there are foot bridges, it is predicted that their utilization will be limited because of dangers due to use by large numbers of people. A large group of over 400,000 persons is thought to converge in JR Osaka Station area, and a large crowd will remain in this area for a long period of time.

In the future, it is necessary to improve the system so that it can consider factors such as what is the best way to accommodate crowds of evacuees, and how many buildings are required as evacuation base facilities, etc. on the assumption that a situation like the one described in this paper occurs.

VI. CONCLUSION AND FUTURE WORK

The purpose of this research is to develop an evacuation guidance method for the area around JR Osaka Station, and we have proposed a system that is able to simulate how evacuees will act in this area as the first step towards that purpose. So far, we have developed a simulator of evacuation behavior which targets only the people on the ground level. Using this, we conducted a simulation targeting the area around JR Osaka Station and Umeda Station in various situations. It is predicted that evacuation simulation using computer is effective because it is problematic to conduct an experiment of evacuation guidance on a real-life scale in the crowded JR Osaka Station area.

In this simulation, we did not deal with the interaction between people trying to evacuate from buildings, the subway and the underground shopping center to the outside and people who are already outside. In cases where large crowds stay on the ground, it is predicted that evacuees will

not be able to go easily outside from buildings and the underground shopping area. Therefore, it is predicted that many will stay in the places around the station. At the same time, it is possible that the psychological pressure caused by the short time period until a tsunami hits will cause panic. Therefore, we plan to expand the functions of this system in order to be able to simulate cases where evacuees will go out from buildings to take refuge at ground level, as the next step in our research, and we consider the function of some disaster's psychological reaction in this simulation.

ACKNOWLEDGMENTS

We would like to extend our sincere thanks to KOZO KEIKAKU ENGINEERING Inc.

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