DEVELOPMENT OF TSUNAMI REFUGE PETRI-NET SIMULATION SYSTEM UTILIZABLE IN INDEPENDENCE DISASTER PREVENTION ORGANIZATION

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ABSTRACT :

A lot of lives were lost in the tsunami following the Sumatra earthquake on December 26, 2004. Moreover, many big earthquakes and tsunami have occurred, and caused serious damage also in Japan in the past. The Nankai earthquake has regularly occurred at intervals of between 100 and 150 years. It is predicted that the next Nankai earthquake will occur with a probability of about 50% within the next 30 years. The best method for protecting human life against tsunami is to smoothly evacuate inhabitants to safe places until after a tsunami has passed. It is necessary to always heighten inhabitant's awareness of tsunami damage and to practice emergency evacuation drills with all inhabitants. However, at present it is difficult to raise awareness because tsunami damage can't be imagined easily. In this study, we developed a practical tsunami refuge Petri-net simulation system for independent disaster prevention organizations as a tool to heighten consciousness of potential tsunami damage. In this system, walking ability of each inhabitant, road blockage due to collapse of building and display function of refuge situation are considered. Simulations of evacuation behavior of inhabitants were carried out based on Petri-net. From the results of this study, it was found that the simulation system developed by the authors is an effective tool for inhabitants to become more aware of tsunami prevention in their region. Our method can be used both positively and practically for education and training in tsunami refuge of inhabitants.

KEYWORDS: tsunami evacuation, simulation system, walking ability, Petri-net, Nankai earthquake

1. INTRODUCTION

Nankai earthquake is a typical huge marine earthquake which is predicted to happen in the near future in Japan. The probability of its occurrence within the next 30 years is predicted to be about 50 %. In general, damage from a huge marine earthquake is caused not only due to destruction of structures but also tsunami. The most effective means to save human lives from tsunami is to have inhabitants evacuate to refuge places as soon as possible. In order to perform evacuation activities smoothly, evacuation drill in which all inhabitants participate must be carried out periodically. Though emergency evacuation drill is very important to find the problems of actual refuge and make people have a sense of crisis, it is difficult to perform such drills with all inhabitants present. Moreover, completion time of refuge is effected by differences of walking ability of each inhabitant. In this study, we developed a tsunami refuge Petri-net simulation system considering walking ability of each inhabitant and road blockage by collapse of building. Refuge action of each inhabitant is expressed using the Petri-net. A questionnaire survey was carried out in order to estimate walking ability of each inhabitant. We applied this system to Tsunomine district along the coastal area of Anan City, which is located in the eastern part of Shikoku island in Japan, and examined the usefulness of it.

2. OUT LINE OF SIMULATION SYSTEM OF TSUNAMI EVACUATION

The flow chart of tsunami refuge Petri-net simulation system developed in this study is shown in Fig.1.

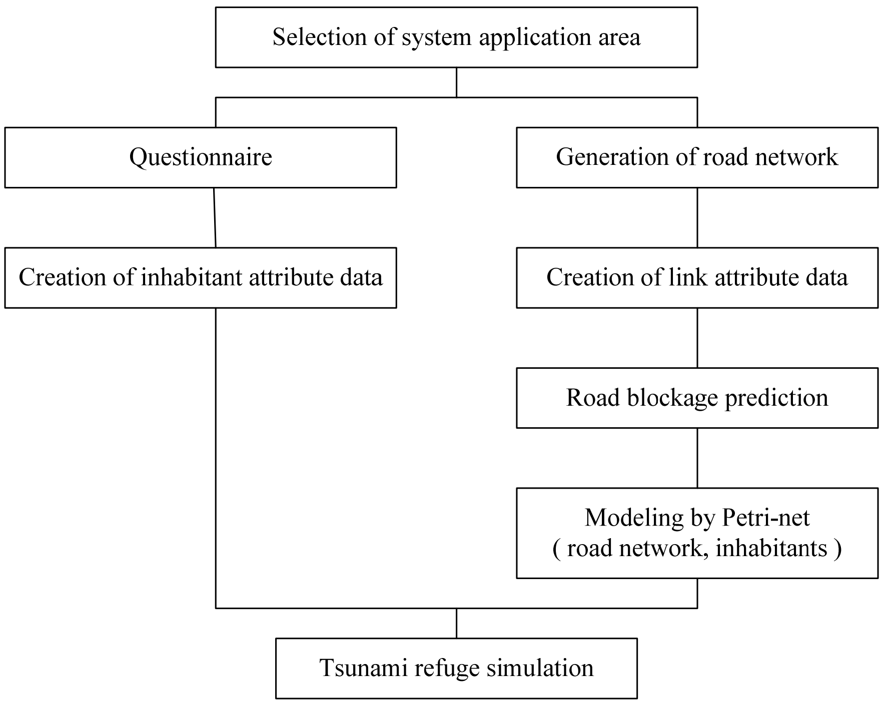


Figure 1 Tsunami refuge simulation

3. SIMULATION AREA

We applied tsunami refuge Petri-net simulation system developed by us to Tsunomine district in Anan City (vertical line part of Fig.2) which is one of the highest tsunami risk areas. Moreover, independent disaster prevention organizations were established. There are some active organizations which have regular meetings.

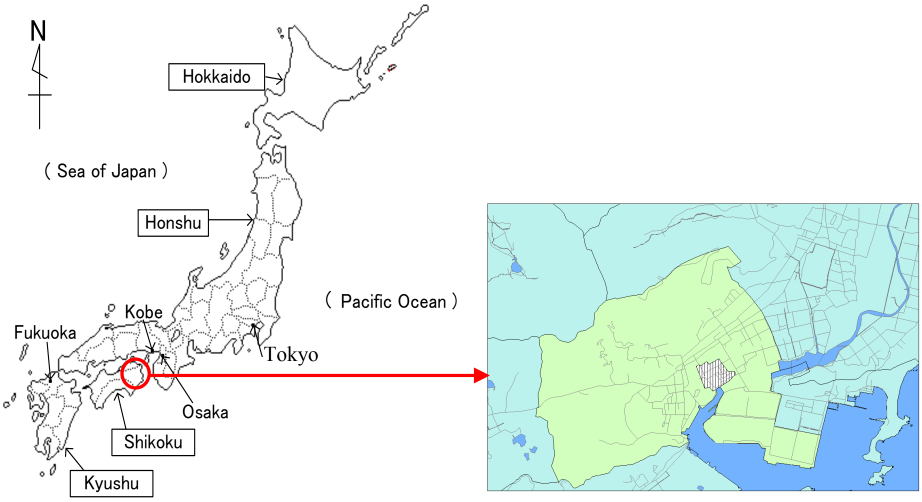


Figure 2 Target area of simulation (vertical line part)

4. QUESTIONNAIRE SURVEY ON ATTRIBUTE OF INHABITANTS AND HOUSES

The questionnaire was conducted in order to obtain inhabitant and house attributes. Questions were related to inhabitants attributes such as ambulatory ability, age, etc. Ambulatory ability was made up of the three following categories: “normal walking”, “slow walking” and “difficulty in walking”. The question about house attribute was the location of inhabitant’s house etc.

5. GENERATION OF ROAD NETWORK AND CREATION OF ATTRIBUTE DATA OF INHABITANTS AND HOUSES

The road network in simulation area was created using GIS. The road network was created to be based on a digital map. The network is made up of links and nodes numbering 648 and 667, respectively. As shown in Fig. 3, nodes were taken as houses, crossroads, turn in the road and refuge place. Moreover, in order to more accurately represent movement of inhabitants by Petri-net, nodes are created so that link may be set to under 10m. Links were taken as roads, the approach to the destination and each house. As attribute data, link attribute data and inhabitant attribute data were created. Link attribute data was created for street width and number of roadside buildings. Inhabitant attribute data was created for walking speed and starting point based on the questionnaire.

6. PREDICTION OF ROAD BLOCKAGE

Blockage probability was calculated in order to perform network analysis in consideration of road blockade due to collapse of wooden houses. When blockage probability is 40% or more, it is considered as blockage which means inhabitants have to select an alternative route. Width of road is classified into width<4m, 4≦width<8m and width≦8m. Blockage probability of width<4m and 4≦width<8m are calculated using the blockage probability calculation model shown in Fig.4. Blockage probability of width≦8m is 0%. Forecast of road blockage result is shown in Fig.5.

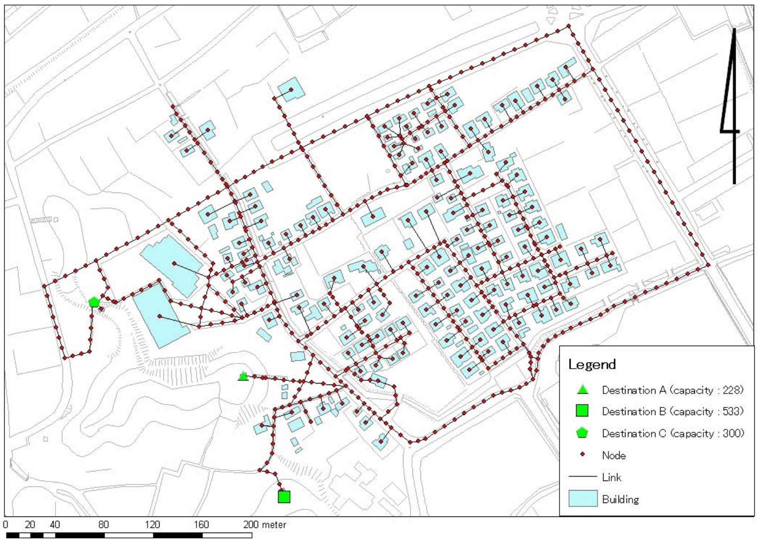
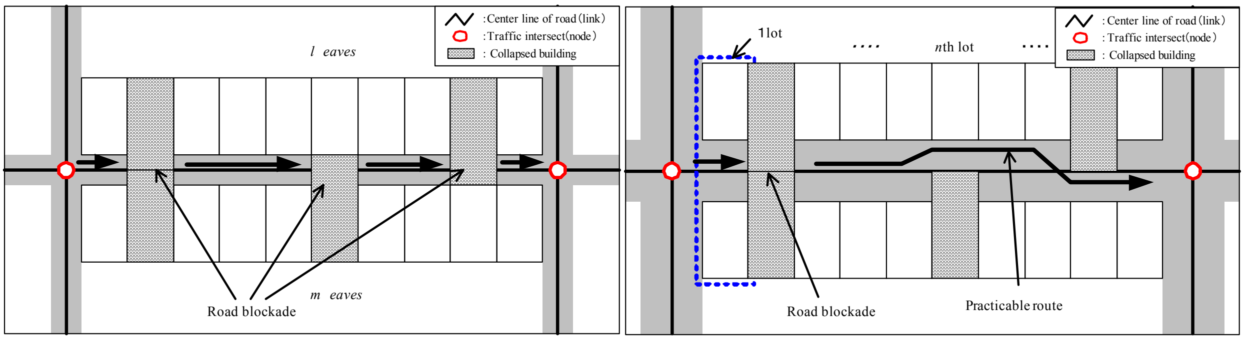


Figure 3 Road network of target area



No.1(width<4m) No.2(4≦width<8m)

Figure 4 Street blockage model

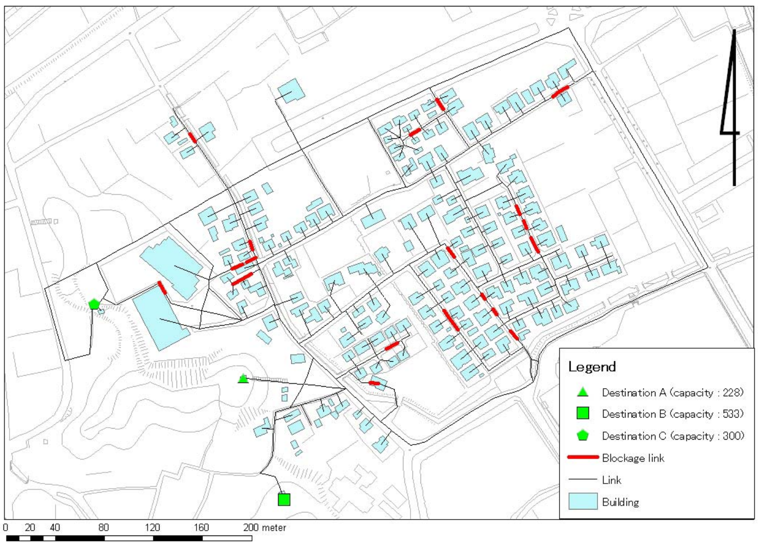


Figure 5 Forecast of road blockage result

7. MODELING OF ROAD NETWORK AND INHABITANTS USING PETRI-NET

7.1. Petri-net

In this study, tsunami refuge Petri-net simulation is performed. Petri-net is a mathematical model for expressing a dispersive, asynchronous and parallel system. As shown in Fig.6, it is constituted by place, arc, transition and token. If conditions are fulfilled, transition will work (it is called “firing"), token is eliminated from input place, and is added to output place. Dynamic action is expressed when token moves between input place and output place.

7.2. Modeling using Petri-net

As shown in Fig.7, road network and inhabitants were modeled by Petri-net. Each node was modeled by one place, respectively. Each link applicable to road was modeled with two transitions and four arcs. Here token was moved bi-directionally between two places. This is because the direction a token moves is determined by direction of arc. Each link applicable to approach to each house was modeled with one transition and two arcs. This was done because inhabitants who have taken refuge don’t return to houses. Each inhabitant is modeled by one token, respectively.

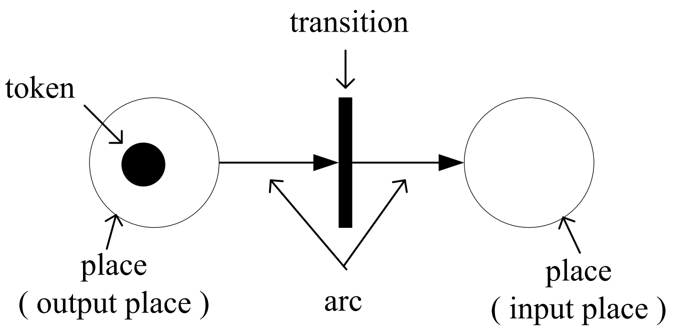


Figure 6 Composition of Petri-net

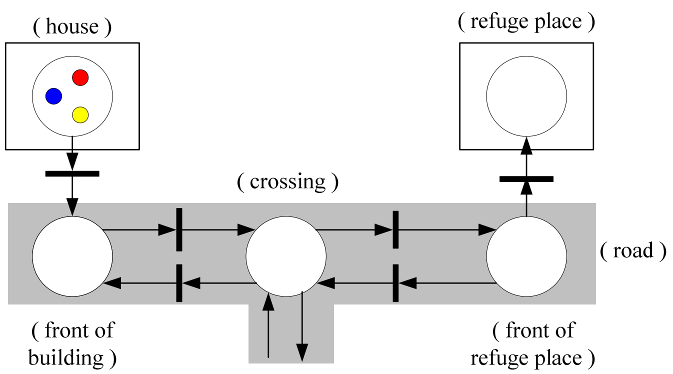


Figure 7 Modeling using Petri-net (road network & inhabitants)

8. RESULT OF TSUNAMI EVACUATION SIMULATION

In this study, tsunami refuge Petri-net simulation was performed considering walking ability of each inhabitant and road blockage by collapse of building. Below, preconditions and simulation results are shown.

8.1. Preconditions for tsunami evacuation simulation

Standard walking speed of each inhabitant was classified according to age as shown in Table 1. Moreover, walking speed of child from 0 years old to 3 years old is the same as parents. Because, it is assumed that parents hold children and move. Walking speed of token is changed depending on the density of each link based on the relation between crowd density and walking speed, as shown in Table 2. The maximum density of refugees in every link is assumed to be 6.5 people/m^2. Therefore the maximum number of persons who can advance into each link is calculated by Eqn. 8.1. The number of people in each link does not exceed this value. In addition, walking speed is decreased on stairs and slopes.

$$\text{the maximum number of persons who can enter each link} = w \times l \times 6.5 \quad (8.1)$$

Where w = street width (m), l = link length (m).

In this tsunami evacuation simulation, inhabitants move to refuge place from each house through the shortest distance on foot. As mentioned above, when density of refugees in a link is 6.5 people/m^2 or more, any token does not enter that link. And token remains at present place, or approaches an other link. When people who can't enter some link choose a detour, they do not return to the link which they passed immediately before, except for in the case that other links do not exist. The number of target inhabitants of a tsunami evacuation simulation is 374 persons. The number of the inhabitants who replied to the questionnaire is 308 persons, and the number of inhabitants is 66 persons in case of assuming that three persons live in each building except vacant houses, and the houses where resident replied to the questionnaire, etc. in system application area.
Tsunami refuge simulation is performed for four patterns with combination of three conditions as shown in Table 3. In the case that transfer unit is a family, standard walking speed is changed into the speed of the slowest person in the family. In the case that transfer unit is an individual, standard walking speed is determined from Table 1. In the case that standard walking speed is independent of age, standard walking speed of all inhabitants is set as 1.3m/s. Occurrence time of an earthquake is early morning. Because there is a high probability that inhabitants are in houses. From the attainment time prediction result of tsunami, tsunami reaches at system application area 26 minutes after occurrence of an earthquake. There are no inhabitants who are killed or injured by destruction of houses etc. All inhabitants can start refuge 5 minutes after occurrence of an earthquake. Capacity of refuge place is shown in the legend of Fig.3. Inhabitants move to the nearest refuge place. If Inhabitants can't go to the nearest refuge place, they go to the secondary nearest refuge place.

Table 1 Standard walking speed of each inhabitant

Age (year)	Walking speed (m/s)	Age (year)	Walking speed (m/s)
0 – 3	Same walking speed as parents	19 – 25	1.5
4 – 6	0.8	26 – 39	1.3
7 – 12	1	40 – 49	1.2
13 – 15	1.2	50 – 64	1
16 – 18	1.3	65 –	0.8

Table 2 Correlation of density and walking speed

Density of refugees (people/m^2)	Walking speed
– 1.5	Standard walking speed (see Table 1)
1.5 – 3.8	0.5m/s
3.8 – 6.5	0.2m/s
6.5 –	No approach

Table 3 Simulation pattern

Pattern	Road blockage	Standard walking speed	Transfer unit
(a)	×	×	familly
(b)	○	×	familly
(c)	×	○	familly
(d)	×	×	individual

○ : consideration
× : ignorance

8.2. Simulation results

In this study, tsunami refuge simulations for four patterns shown in Table 3 were performed. Refuge completion rate curve for pattern (a), (b), (c) and (d) are shown in Fig.8 respectively. As for pattern (a), refuge of the first inhabitants is completed about 2 minutes after start of refuge. Moreover, refuge of about 90% of inhabitants was completed within about 9 minutes after start of refuge. Fig.9 shows transition of moving situation of inhabitants from start of refuge to completion. It is understood that each inhabitant moves toward the refuge place from each house as shown in Fig.9. Completion time of refuge and completion number of persons of refuge for each pattern are shown in Table 4. In pattern (b), all inhabitants can not successfully seek refuge due to road blockage. But in patterns (a), (c) and (d), which aren't considered road blockage, all inhabitants can seek refuge it. Increment of completion rate of refuge after 4 minutes from refuge start is significantly less in pattern (b) than other patterns, because inhabitants can't pass the shortest course due to road blockage and must take a detour. Although pattern (a) has more inhabitants with slow walking speed than pattern (d), there is no difference in completion time of refuge of all inhabitants. Because same token has taken time most in both patterns (a) and (d). In addition, completion rate of refuge for every time is the largest in pattern (c) and the smallest in pattern (a) respectively as shown in Fig.8.

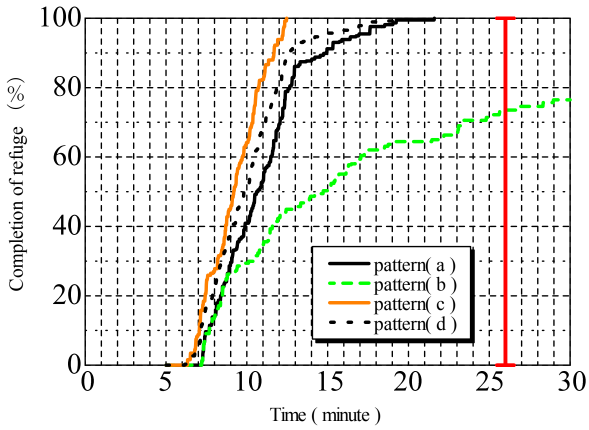


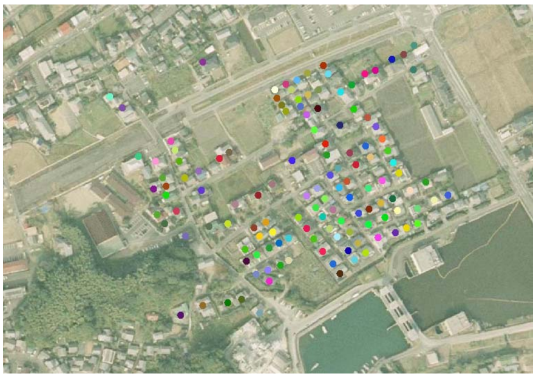
Figure 8 Refuge completion rate curve (Pattern (a),(b),(c) and (d))

Table 4 Simulation results

pattern	Time reguired for refuge completion	Number of people who evacuated
(a)	21' 36"	374 (100 %)
(b)	×	275 (74 %)
(c)	12' 28"	374 (100 %)
(d)	21' 36"	374 (100 %)

9. CONCLUSIONS

In this study, a method of tsunami refuge Petri-net simulation system in consideration of walking speed of each inhabitant, road blockage and method of questionnaire survey on attributes of inhabitants and houses were developed. We examined the validity of this system by applying it to a part of Tsunomine district, Anan City, Tokushima Prefecture in Japan. From the simulation results, it was found that walking ability of inhabitants has a big influence on simulation results and the adequacy for location and capacity of refuge place designated by the local government could be accurately assessed by using the model proposed here.



1 : After five minutes (Start of refuge)
(Refuge completion rate: 0%)

2 : After eight minutes
(Refuge completion rate: 9.9%)

3 : After eleven minutes
(Refuge completion rate: 49.1%)

4 : After fourteen minutes
(Refuge completion rate: 90.9%)

5 : After seventeen minutes
(Refuge completion rate: 96.9%)

6 : After twenty two minutes and six seconds
(Completion of refuge, refuge completion rate: 100%)

Figure 9 Process of refuge in Pattern (a)

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