2018 Joint 10th International Conference on Soft Computing and Intelligent Systems and 19th International Symposium
on Advanced Intelligent Systems

Nonstationary Markov Chain Model for Stopping-by Behavior on the way to Tsunami Evacuation Site

Kentaro Kumagai
National Institute for Land and Infrastructure Management
Ministry of Land, Infrastructure, Transport and Tourism
Yokosuka, Kanagawa, Japan
kumagai-k27n@mlit.go.jp

Abstract— **When tsunami occurs, residents and visitors in coastal area should evacuate as soon as possible to an evacuation site or a safe building, in order to ensure safeness from tsunami inundation. However, for various reasons, it has been frequently observed in the past disasters that people did not evacuate immediately to the evacuation site, and lost time due to late departure or stopping-by behavior on the way to the evacuation site. In this study, Markov chain model for stopping-by behavior in tsunami evacuation with nonstationary transition probability was developed. The model includes three state, that are a state of being at home, a state of being out from home for one's business, and a state in an evacuation site. As a result of simulation, it was found that approximately 21 % of evacuees are exposed to high risk of human safety from tsunami inundation, in condition that tsunami arrival time is at 900 s after an earthquake. And it was also found that proportion of evacuees who are exposed to high risk from tsunami inundation would decrease at approximately 4 %, when residents who were not at home go evacuation sites directly, instead to go back home.**

Keywords- Markov chain, stopping-by behavior, tsunami evacuation, nonstationary transition probability

I. INTRODUCTION

When tsunami occurs, residents and visitors in coastal area should evacuate as soon as possible to evacuation sites outside of the inundation area or to safe buildings, in order to secure safety from the tsunami risk. However, for various reasons, it has been frequently observed in the past disasters that people lost time due to late departure or stopping-by behavior on the way to the evacuation sites, although they felt strong motion of earthquake. For example, Isagawa et al. [1] conducted a survey on the behavior of residents in coastal areas after the 2011 Tohoku earthquake. They found that approximately sixty percent of people who were not at home when the earthquake occurred went their home before going to evacuation sites. Isagawa et al. pointed out that reasons to go home were to confirm the damage of the home due to the earthquake, to check the safety of the family members, to pick up baggage, and others. From a viewpoint to secure safety, it is necessary to evaluate the risk of stopping-by behavior and to obtain quantitative knowledge on the relationship between evacuation safety and the proportion of people who perform high-risk behaviors.

Although it seems to be important to assess such risk, reports have apparently not been published which related to quantitative assessment on the risk of stopping-by behavior in tsunami evacuation. Hanabusa et al. [2] wrote about their micro-simulation program of evacuation, and they said that their geographic dataset for the simulation is able to include 'POI' (Point of Interest) information to distinguish places where evacuee will stop by. But they did not apply their simulation model to stopping-by behavior explicitly in the paper. Based on these recognition above, to propose a new methodology to evaluate the risk of stopping-by behavior on the way to evacuation sites will be important.

Supposing state of evacuees in the aftermath of earthquake to be able to categorized into several state, such as a state of being at home, a state of being out for his or her business, a state of staying in an safe place, it seems that it could be reasonable to represent behavior of evacuees as stochastic processes divided into finite state. And it also seems that there is not so much impossibility to introduce another assumption that when residents are noticed tsunami warnings or tsunami advisories, many of them change their behavior and start evacuation to go to the safer places. Therefore the stochastic process model proposed above should have a characteristic that the transition probability is nonstationary.

Figure 1 shows an example of transition diagram of Markov chain, consisted of three circles (S_1, S_2 and S_3) and arrows, which indicate state and transition probabilities, respectively. $P_{i,j}$ (i, j= 1, 2, 3) attached on each arrow represent values of probability of transition from a state i to another state j, or probability of staying in a certain state, if $i = j$. Usually, the values of $P_{i,j}$ are homogeneous in time, as Singer [3] pointed out "With a few exceptions, most attempts to model individual choice behavior with Markov and related models have interpreted "Markov" to mean time-homogeneous Markov." Although it seems to be that the research situation has not changed significantly since then, there are some unique researches to develop Markov chain model considering with nonstationary transition

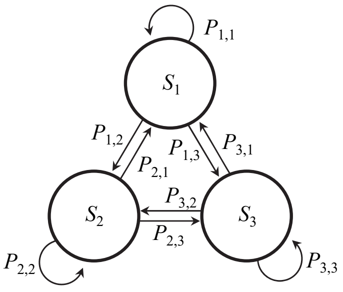

Figure 1. Example of transition diagram.

978-1-5386-2633-7/18/$31.00 ©2018 IEEE
DOI 10.1109/SCIS-ISIS.2018.00273

probability. For example, Chiba et al. [4] conducted a numerical simulation using a nonstationary Markov chain in condition that the values of $P_{i,j}$ were revised step by step at a fixed time-interval. They repeated calculation at an iterative routines of the simulation, and draw figure of time-series of probabilities of each state. Their methodology will be helpful to simulate behavior of evacuees, because the stochastic process in this study have to be nonstationary. In addition, it should be noted that Markov chain model needs an additional assumption that state of the future is depend only on the current situation and transition probability, but not on the situation in the past, because of its definition.

In this study, nonstationary Markov chain model was applied for stopping-by behavior of evacuees on the way to tsunami evacuation site. In the first half of Chapter II, a simple conceptual model of the stopping-by behavior is proposed and results of the simulation is shown, as a basic study. And in the latter part of the chapter, a practical model is developed which intended to apply the model to more complex phenomena than the former one. Chapter III and IV are discussions and conclusions, respectively.

II. MODELS FOR STOPPING-BY BEHAVIOR

A. Simple Conceptual Model

Figure 2 is a transition diagram of a conceptual model of the stopping-by behavior, proposed as the simplest model. It includes three state, S_A, S_B and S_C. They correspond to a state of being at home, a state of being out from home for one's business, and a state in evacuation site, respectively.

When the earthquake occurs, residents and visitors are requested to evacuate from S_A or S_B to S_C. According to Isagawa et al. [1], the value of $P_{A,B}$ was 0.6. Because there were no research results available for the remaining values of transition probability, values in the fifth column, Case 4, of Table 1 were used as a trial study. For Case 4, the reference case, the stochastic matrix $\boldsymbol{P}$ was,

$$\boldsymbol{P}=\begin{pmatrix} P_{A,A} & P_{A,B} & P_{A,C} \\ P_{B,A} & P_{B,B} & P_{B,C} \\ P_{C,A} & P_{C,B} & P_{C,C} \end{pmatrix}=\begin{pmatrix} 0.20 & 0.60 & 0.20 \\ 0 & 0.50 & 0.50 \\ 0 & 0.05 & 0.95 \end{pmatrix} \quad (1)$$

The second to the fourth and the rightmost columns in the table were values for parametric studies: the value of $P_{A,B}$ was set from zero for the minimum to 0.8 for the maximum, to evaluate the relationship between the high-risk behavior and evacuation safety. Although in Chapter 1 the author pointed out about the nonstationary characteristic of the transition probability, $\boldsymbol{P}$ was assumed to be constant in this section for simplicity of the model. The nonstationary characteristic of $\boldsymbol{P}$ will be discussed in the following section.

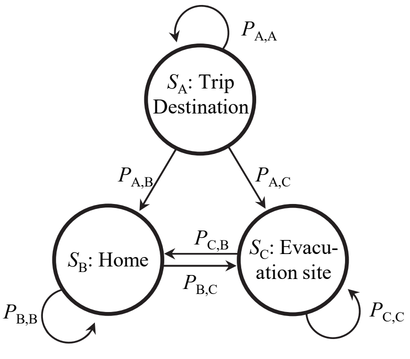

Figure 2. Transition diagram of simple conceptual model.

Δt in Table 1 is a transition time from a state i to j, in condition that i is not equals to j. According to City bureau of MLIT [5], at the 2011 Tohoku earthquake, the evacuation distance was less or equals to approximately 600 m for 80 % and more evacuees. In case that walking speed is 1 m/s, the time to walk 600 m is equals to 600 s. The most time consuming transition path in Figure 2 was a path from S_A to S_B to S_C. Based on the fact and knowledge above, the average time to transit from S_A to S_B and S_B to S_C was assumed to be 300 seconds, respectively: e.g. it took five minutes in average to go back from trip destinations, such as places of employment, shopping centers or schools, to one's home. For simplicity of the model, the time to transit from S_A to S_C was also assumed to be 300 s. Thus, Δt was set to be 300 s.

In case that residents and visitors were located in states A, B and C at time t in the ratio a, b and c, respectively, the distribution of state $\boldsymbol{x}$ at time t was defined as

$$\boldsymbol{x}(t) := (a, b, c)$$

According to MLIT [5], at the 2011 Tohoku earthquake, approximately 60 % of people were at their home. Then a and b were set to be 0.4 and 0.6, respectively. $\boldsymbol{x}(t + \Delta t)$ was calculated as follows:

$$\boldsymbol{x}(t + \Delta t) = \boldsymbol{x}(t)\boldsymbol{P} \quad (2)$$

Figure 3 shows time-series values of a, b and c for Case 4 in t = 0 to 3,600 s as a result of the simulation. If tsunami arrives at $t = t_a$, it is possible to evaluate evacuation safety, referring to the value of c at $t = t_a$. For example, according to the Japan Meteorological Agency [6], at Miyako city which is one of the major cities in the affected areas of the 2011 Tohoku earthquake, t_a was 15 minutes (900 s) [1] after the earthquake. At t = 900 s, the

Table 1. Conditions and constants for simple conceptual model

Case No.	1	2	3	4 (Reference case)	5
$P_{A,A}$	0.20				
$P_{A,B}$	0	0.20	0.40	0.60	0.80
$P_{A,C}$	0.80	0.60	0.40	0.20	0
$P_{B,B}$	0.50				
$P_{B,C}$	0.50				
$P_{C,B}$	0.05				
$P_{C,A}$	0.95				
Δt	300 s				
Ratio of Evacuees in S_A, S_B and S_C at t = 0	40 %, 60 % and 0 %				

---

[1] Among the observation points with the record of the arrival time of the first wave listed in Table 2.2.1 of the reference 6, ground observation points were extracted by excluding offshore observation points. And a point which recorded the fastest arrival time was extracted among the ground observation points.

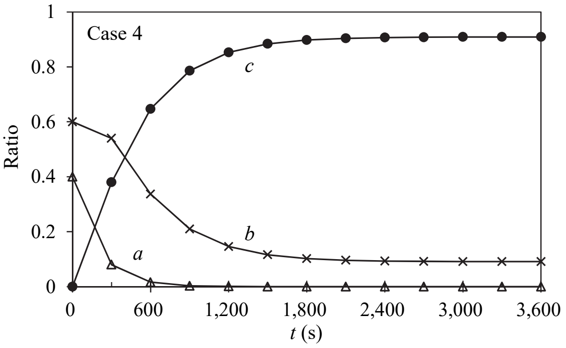

Figure 3. Time-series of a, b and c in Case 4.

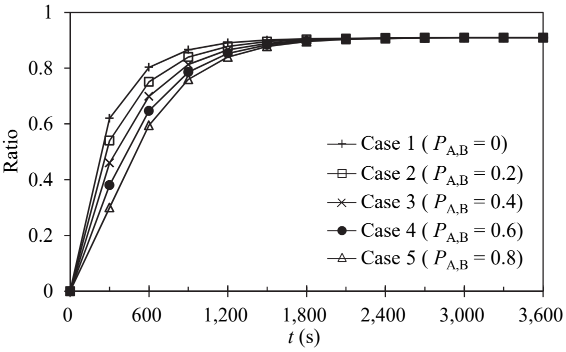

Figure 4. Time-series of c for Cases 1 to 5.

value of c was 0.786, and then 1 - c was equals to 0.214. As a result of this simple study, it was shown that approximately 21 % of evacuees had not yet arrive evacuation sites when the tsunami arrived, and they were exposed to high risk of human safety from tsunami inundation.

Figure 4 is time-series of values of c for Cases 1 to 5. At t = 900 s, the value of c was varied between 0.760 and 0.866, depending on the value of $P_{A,B}$. For example, in Case 1, $P_{A,B}$ was set to be zero, c was 0.866, and 1 - c was equals to 0.134. By comparing the results of Case 1 and Case 4, it was estimated that ratio of evacuees who are exposed to high risk of tsunami inundation would decrease from 21.4 % to 13.4 %, when $P_{A,B}$ decreases from 0.6 to zero. As described above, the simple conceptual model of the stopping-by behavior was proposed, and numerical simulations for the quantitative analysis were conducted about the relationship between evacuation safety and the proportion of people who will perform high-risk behaviors.

It should be noted that, in this section, values of $\boldsymbol{P}$ were set based on the empirical data of the specific event and on some assumptions, but there would be uncertainties on the values. For improvement of dealing with uncertainties on values, further investigation is necessary.

B. Practical Model

The simple model have been proposed in the previous section, but several bold assumptions were necessary because simplicity of the model was prioritized. In this section, a practical model will be proposed to improve the previous model, although its structure is slightly more complicated than that of the previous model.

Figure 5 is a transition diagram of a new model, 'the practical model' of the stopping-by behavior. One of the improvements of the practical model was to make the time resolution, Δt, finer than that of the previous model. The value of Δt for the previous model was fixed to 300 s. In contrast, the value of Δt for the practical model can be set to any time step depending on the numbers of small circles in the figure, such as S_1, S_2, ..., S_l, S_{l+1}, ..., $S_{l+\mathrm{m}}$, $S_{l+\mathrm{m}+1}$, ..., $S_{l+\mathrm{m}+2\mathrm{n}}$. Values of l, m and n are integers equal to or more than zero. In order to set Δt as 60 s, let l, m and n set to be four. For further reference, l, m and n can be different from each other if an appropriate stochastic matrix of transit probabilities is prepared. For example, in case that distances from S_A to S_B, S_A to S_C and S_B to S_C are different each other, the values of l, m and n will be different from each other.

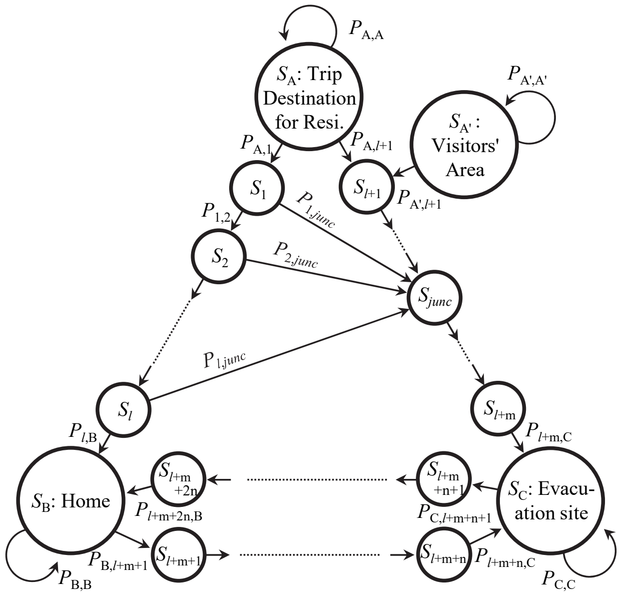

Figure 5. Transition diagram of practical model.

Other improvement of the practical model was to distinguish visitors who are unfamiliar with the place from residents who have enough information related to evacuation. In the figure, S_A is for residents, and $S_{A'}$ is for visitors. For residents, function of arrows $P_{A,A}$, $P_{A,1}$ and $P_{A,l+1}$ are same to that of the arrows $P_{A,A}$, $P_{A,B}$, and $P_{A,C}$ in Figure 2. For visitors, $S_{A'}$ has two arrows, and the two represent values of probability to start evacuation from state $S_{A'}$ to S_C, and probability to stay in the initial state $S_{A'}$. The value of $P_{A',A'}$ should be larger than $P_{A,A}$, because it seems that visitors tend to be more unfamiliar with the place than residents, and delayed to start evacuation.

Because Δt was set to be 60 s, values of $P_{A,A}$, $P_{A,1}$ and $P_{A,l+1}$ should be revised from the values of $P_{A,A}$, $P_{A,B}$, and $P_{A,C}$ in Table 1 of the previous model. In Case 4 of the previous section, the values of $P_{A,B}$ and $P_{A,C}$ were set to be 0.6 and 0.2, respectively. If $P_{A,B}$ was equals to 0.6, it meant that 60 % of people in S_A leave from S_A to S_B within the first 300 s. When $P_{A,1}$ and $P_{A,l+1}$ in Figure 5 are denoted as characters p and q, respectively, ratio of people leave from S_A to the direction of S_B within the first 5 minutes, $f(p, q)$, and ratio from S_A to the direction of S_C, $g(p, q)$, are calculated by the following equations:

$$f(p, q) = p+(1-p-q)p+(1-p-q)^2p+(1-p-q)^3p+(1-p-q)^4p \quad (3)$$

$$g(p, q) = q+(1-p-q)q+(1-p-q)^2q+(1-p-q)^3q+(1-p-q)^4q \quad (4)$$

Table 2. Stochastic matrix of practical model for Case 4'.

States	A	A'	B	C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	0.725 (0.725)				0.206 (0.165)				0.069 (0.110)											
A'		0.871					0.129													
B			0.871 (0.833)										0.129 (0.167)							
C				0.990													0.010			
1						1 (0.80)				(0.20)										
2							1 (0.80)			(0.20)										
3								1 (0.80)		(0.20)										
4			1 (0.80)							(0.20)										
5										1										
6											1									
7												1								
8				1																
9														1						
10															1					
11																1				
12				1																
13																		1		
14																			1	
15																				1
16			1																	

Note: This table shows the stochastic matrix ***P*** and ***P'*** in case that l = m = n = 4. The values without parentheses indicate the value for ***P***, and that with parentheses are for ***P'***. If there is only one value without parentheses written in a cell, the number intends that the value of ***P'*** was the same as the value of ***P***. A blank cell means that the value of the cell is zero.

Table 3. Simulation cases for the practical model.

(1) $P_{A,1}$ and $P_{A,5}$

Case No.	1'	2'	3'	4'	5'	Note
$P_{A,1}$	0 (0)	0.069 (0.055)	0.138 (0.110)	0.206 (0.165)	0.275 (0.220)	$:= p$
$P_{A,5}$	0.275 (0.275)	0.206 (0.220)	0.138 (0.165)	0.069 (0.110)	0 (0.055)	$:= q$

(2) $f(p, q)$ and $g(p, q)$

Case No.	1'	2'	3'	4'	5'	Note
$f(p, q)$	0 (0)	0.20 (0.16)	0.40 (0.32)	0.60 (0.48)	0.80 (0.64)	Eq. (3)
$g(p, q)$	0.80 (0.80)	0.60 (0.64)	0.40 (0.48)	0.20 (0.32)	0 (0.16)	Eq. (4)

In view of accordance with conditions of Case 4 of the previous model, $f(p, q)$ and $g(p, q)$ were,

$$f(p, q) = 0.6 \tag{5}$$

$$g(p, q) = 0.2 \tag{6}$$

Since the simultaneous quintic equations (5) and (6) were difficult to solve for p and q by algebraic method, approximate calculation method was adopted to solve the equations. As a result, p and q were set to be 0.206 and 0.069, respectively. Using calculation methods similar to the method above, the values of $P_{B,l+m+1}$ and $P_{C,l+m+n+1}$ were set to be 0.129 and 0.010, respectively (See Appendix). Value of $P_{A',l+1}$ should be smaller than the sum of p and q, 0.275, because visitors tend to be more unfamiliar with the place than residents, and will delay to start evacuation. Although there were no data available for the value of $P_{A',l+1}$, the value was set to be 0.129 as a trial study. The value means that 50 % of visitor leave from S_A to the direction of S_C within the first 300 s. At t = 0, the values for the other arrows in Figure 5 except for $P_{1,junc}$, $P_{2,junc}$, ..., $P_{l,junc}$ were all set to be 1. As long as the values are equals to 1, evacuees automatically proceed to the next circle every time when the time advances by Δt. At t = 0, the values of $P_{1,junc}$, $P_{2,junc}$, ..., $P_{l,junc}$ were all set to be zero.

The other improvement of the practical model was about nonstationary transition probability. In case that residents were located in states S_A, $S_{A'}$, S_B, S_C, S_1, ..., S_{l+m+2n} at time t in the ratio a, a', b, c, x_1, ..., x_{l+m+2n}, respectively, the distribution of state $\boldsymbol{x}$ was defined as

$$\boldsymbol{x}(t) := (a, a', b, c, x_1, ..., x_{l+m+2n})$$

$\boldsymbol{x}(0)$ was set to be as follows, in view of accordance with the parameters for the previous model. Because there were no research results available for the value of a' at t = 0, it was assumed that a' at t = 0 was equals to 10 % of evacuees as a trial study.

$$\boldsymbol{x}(0) = (0.3, 0.1, 0.6, 0, 0, ..., 0) \tag{7}$$

Supposing tsunami warning or tsunami advisory will be issued at $t = t_w$, it seems that it is reasonable to assume that the transition probability will change around $t = t_w$. Let $\boldsymbol{P}$ stands for the stochastic matrix at $t < t_w$, and $\boldsymbol{P'}$ stands

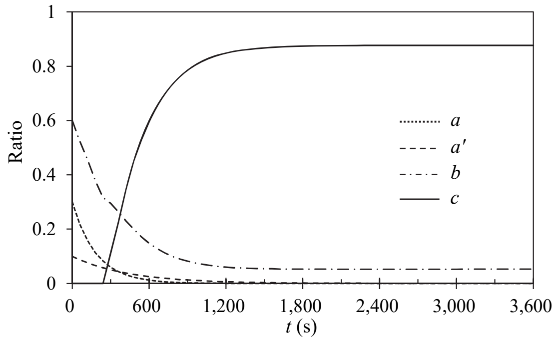

Figure 6. Time-series of a, a', b and c in Case 4'.

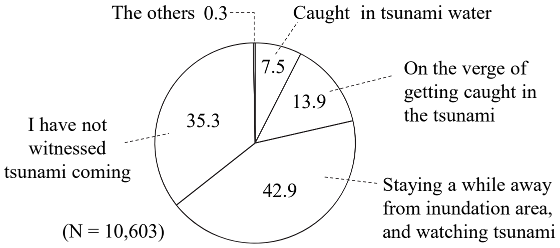

Figure 7. Result of questionnaire survey about experience of the 2011 Tohoku earthquake (MLIT, 2013, [5]).

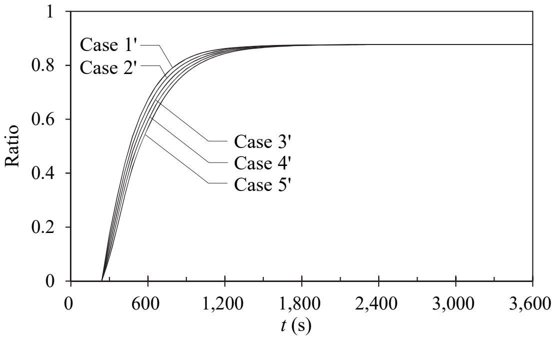

Figure 8. Time-series of c for Cases 1' to 5'.

for the matrix at $t \geqq t_w$. $\boldsymbol{x}(t + \Delta t)$ is calculated by the following equations:

$$\begin{cases} \boldsymbol{x}(t + \Delta t) = \boldsymbol{x}(t)\boldsymbol{P} \quad \text{at } t < t_w & \text{(8a)} \\ \boldsymbol{x}(t + \Delta t) = \boldsymbol{x}(t)\boldsymbol{P'} \quad \text{at } t \geqq t_w & \text{(8b)} \end{cases}$$

Table 2 shows $\boldsymbol{P}$ and $\boldsymbol{P'}$ for the practical model with l = m = n = 4. The values without parentheses in the table indicate the values for $\boldsymbol{P}$, and that with parentheses were for $\boldsymbol{P'}$. If there is only one value without parentheses written in a cell, the number intends that the value of $\boldsymbol{P'}$ was the same as the value of $\boldsymbol{P}$. A blank cell means that the value was zero for both $\boldsymbol{P}$ and $\boldsymbol{P'}$. For example, the value of $P_{\mathrm{A},1}$ decrease from 0.206 to 0.165 after $t = t_w$.

In the model proposed, it is assumed that one fifth of people will modify their behavior when they learn that a tsunami warning or tsunami advisory has been issued. And they move directly to evacuation sites instead of going their homes. For example, if $P_{\mathrm{A},1}$ is equals to 0.206 and the value is stable during 300 s, 60 % of people in S_{A} will start to go to the direction of S_{B} (See the fifth column of Table 3(1) and (2)). Supposing that one fifth of people will modify their behavior, $f(p, q)$ should be decreased from 60 % to 48 %. As a result, the value of $P_{\mathrm{A},1}$ is modified to 0.165. On the other hand, $g(p, q)$ was modified from 20 % to 32 %, because people change their destination from S_{B} to S_{C}. Since there were no knowledge about the value of $junc$ in Figure 5, it was assumed that S_{junc} was S_6 in Table 2, as a trial study.

According to the Japan Meteorological Agency [7], it is expected that tsunami warning or tsunami advisory will be issued within three minutes after an earthquake. Therefore t_w was set to be 180 s. Figure 6 draws time-series of a, a', b, and c in Case 4' as a result of the simulation. At t = 900 s, the value of c was 0.786, and then 1 - c was equals to 0.214. As a result, approximately 21 % of evacuees had not yet arrive evacuation sites when the tsunami arrived, and they were exposed to high risk from tsunami inundation.

It is important to validate the accuracy of the calculation results of the simulation model proposed. Although there was not enough time-series data about arrival time of evacuees to evacuation sites for the past tsunami events, information that can be reference exists. For example, MLIT [5] conducted questionnaire survey with residents who lived in the inundation area of the 2011 Tohoku earthquake, and they reported that the proportion of evacuees who were caught in tsunami water, and evacuees who were on the verge of getting caught in the tsunami were 7.5 % and 13.9 %, respectively (Figure 7). Sum of the both values is equals to 21.4 %. Because the simulation result of the proportion of evacuees who were exposed to high risk from tsunami inundation was approximately 21 %, it seems that the value obtained by this simulation is consistent with the fact observed at the 2011 Tohoku earthquake.

Table 3(1) shows five cases for parametric studies. The value of $P_{\mathrm{A},1}$ was set from zero for the minimum to 0.275 for the maximum at t = 0, to evaluate the relationship between the high-risk behavior and evacuation safety. Figure 8 shows time-series of values of c for Cases 1' to 5'. At t = 900 s, the value of c was varied between 0.773 and 0.824. For example, in Case 1', $P_{\mathrm{A},1}$ was set to be zero, c was 0.824, and 1 - c was equals to 0.176. By comparing the results of Case 1' and Case 4', it was found that proportion of evacuees who are exposed to high risk from tsunami inundation will decrease at approximately 4 %, when $P_{\mathrm{A},1}$ at t = 0 decreases from 0.206 to zero.

Computation Environments for running the simulation were consisted of Intel Core i7-5960X Processor (3.00 GHz, 20MB L3 Cache), 64 GB RAM, and Windows 10. A programming language was Intel Parallel Studio XE 2017 Update 2 Composer Edition for Fortran with Microsoft Visual Studio 2013. The processing time was very short, less than 1 s.

III. DISCUSSIONS

A. *Why not use micro-simulation model ?*

The values of the transition probability of individual behavior are in wide variety depending on evacuees, and it could be more complex in case if the probability has time-

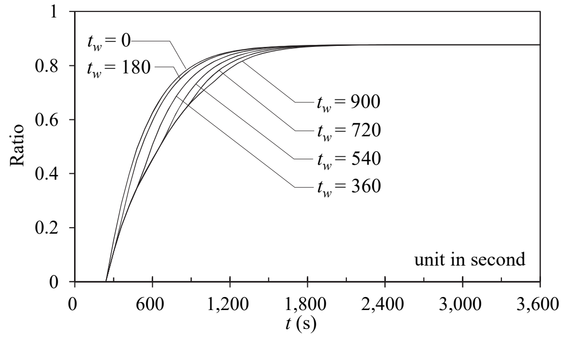

Figure 9. Time-series of c for cases of $t_w = 0$, 180, ..., 900 s.

dependency. A micro simulation model has an advantage of being able to include individual decision process directly in the model. But at the same time, it is necessary to collect or estimate appropriately a lot of parameters. If the number of evacuees to be analyzed is small, it may be possible. But it is difficult if it reaches a large number. Therefore, micro-simulation model was not adopted, and the approach of macro simulation model was applied to the complex system of stopping-by behavior.

It seems that one of the useful ways of utilization of this model will be to assess the current situation and to find a practical solution for tsunami safety, by conducting parametric studies. In view of further utilization, this model should be modified. For example, many parents will go back to their home and will wait until their children come back from schools, instead of starting evacuation without the children. The model proposed in this paper is not enough to simulate such a complicated behavior, and further investigation is necessary.

B. *Effect of tsunami warning*

As mentioned in the previous chapter, it is expected that tsunami warning or tsunami advisory will be issued within three minutes after an earthquake. Figure 6 was the result of the simulation, based on the condition. In this section, parametric studies were conducted hypothetically to evaluate an effect of tsunami warning and tsunami advisory, by using the practical model developed in the section II B.

Figure 9 shows the result of the parametric studies, in condition that the value of t_w was set from zero for the minimum to 900 s for the maximum, at every 180 s. At t = 900 s, the value of c was varied between 0.664 and 0.795. Values for 1 - c are 0.205, 0.214, 0.246, 0.289, 0.333 and 0.336 in case of t_w = 0, 180, 360, 540, 720 and 900, respectively. Based on these results, it was found that, at t = 180 to 720 s, every time when the alarm issuance is delayed by 180 s, the proportion of evacuees who are exposed to high risk from tsunami inundation will increase 3 - 4 percent. And it was also found that, in condition that tsunami arrival time is at t=900 s, there will be little effect of tsunami warning or tsunami advisory if they are issued at t = 720 s and later.

IV. CONCLUSIONS

From a viewpoint to secure safety, it is necessary to evaluate the risk of stopping-by behavior on the way to tsunami evacuation site. Although it seems to be important to assess such risk, no reports have ever been published which related to quantitative assessment on the risk of stopping-by behavior in tsunami evacuation.

In this study, nonstationary Markov chain model was applied for stopping-by behavior of evacuees on the way to tsunami evacuation site.

- A conceptual model of the stopping-by behavior was proposed as the simplest model. It includes three state, that are a state of being at home, a state of being out from home for one's business, and a state in an evacuation site.
- A practical model of the stopping-by behavior was proposed to improve the simple conceptual model. The points improved were the three items, that were to make the time resolution finer than that of the simple conceptual model, to distinguish visitors from residents, and to introduce nonstationary transition probability. As a result of simulation using the practical model, it was found that approximately 21 % of evacuees were exposed to high risk of human safety from tsunami inundation, in condition that tsunami arrival time is at 900 s after an earthquake. And it was also found that proportion of evacuees who are exposed to high risk from tsunami inundation will decrease at approximately 4 %, when residents who were not at home go evacuation sites directly, instead to go back home.
- Parametric studies using the practical model were conducted in order to evaluate an effect of tsunami warning and tsunami advisory. As a result, it was found that, at t = 180 to 720 s, every time when the alarm issuance is delayed by 180 s, the proportion of evacuees who are exposed to high risk from tsunami inundation will increase 3 - 4 percent, in condition that tsunami arrival time is at 900 s after an earthquake.

ACKNOWLEDGMENT

The author would like to express appreciation to the members of Coastal, Marine and Disaster Prevention Division, NILIM for fruitful discussions.

APPENDIX

In Section II B, Δt was set to be 60 s. Values of $P_{B,l+m+1}$ and $P_{C,l+m+n+1}$ should be revised in reference to the values of $P_{B,C}$ and $P_{C,B}$ in Table 1 of the simple conceptual model. In Section II A, the values of $P_{B,C}$ was set to be 0.5, and it meant that 50 % of people in S_B move from S_B to S_C within the first 300 s. When $P_{B,l+m+1}$ in Figure 5 is denoted as a character r, proportion of people who move from S_B to the direction of S_C within the first 5 minutes, $h(r)$, is calculated by the following equation:

$$h(r) = r+(1-r)r+(1-r)^2r+(1-r)^3r+(1-r)^4r \qquad \text{(a1)}$$

In view of accordance with conditions of Case 4 of the simple conceptual model, $h(r)$ was

$$h(r) = 0.5 \qquad \text{(a2)}$$

Approximate calculation method was adopted, and $P_{B,l+m+1}$ was set to be 0.129. By replacing the right-hand side of Eq. a2 with 0.05, $P_{C,l+m+n+1}$ was set to be 0.010.

REFERENCES

[1] T. Isagawa, O. Murao, and R. Ohno, “Coastal residents' behavior in the event of tsunami: Questionnaire surveys before and after the Tohoku Region Pacific Coast Earthquake at Onjuku, Chiba prefecture,” *Journal of Architechture Planning*, Architectural Institute of Japan, 77, No. 681, pp. 2525–2532, 2012.

[2] H. Hanabusa, T. Komiya, R. Horiguchi, and M. Kuwahara, “A Traffic Simulation Framework of Pedestrian and Vehicle for the Evaluation of Evacuation Measures under Natural Disaster,” *Proceedings of Infrastructure Planning*, Japan Society of Civil Engineers, 51, CD-ROM, 7 p., 2015.

[3] B. Singer, “Estimation of Nonstationary Markov Chains from Panel Data,” *Sociological Methodology*, 12, pp. 319–337, 1981.

[4] T. Chiba, H. Hino, S. Akaho, and N. Murata, “Latent structural modeling of steady distribution with time transition,” IPSJ SIG Notes, Information Processing Society of Japan, 2014-MPS-101(6), 6 p., 2014.

[5] City Bureau of Ministory of Land, Infrastructure, Transport and Tourism, “Report on evacuation routes, evacuation facilities and escape guidance assuming tsunami evacuation,” the third edition, pp. 18–65, 2013.

[6] Japan Meteorological Agency, “Report on the 2011 Off the Pacific Ocean Coast of Tohoku Earthquake by Japan Meteorological Agency,” *Technical Report of the Japan Meteorological Agency*, 113, pp. 94-99, 2012.

[7] Japan Meteorological Agency, “Earthquakes and Tsunamis - Disaster prevention and mitigation efforts - ,” pp. 5-6, March 2018, http://www.jma.go.jp/jma/en/Publications/earthquakes_and_tsunamis_brochure.html, Accessed at July 1, 2018.