Extended Abstract for hEART 2018

Dynamic Discrete-Continous Model Incorporating Heterogeneity of Time Constraint for Analysis of Evacuation Networks under Disaster

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1 Introduction

In this research, we proposed a dynamic discrete-continuous model and designed algorithm for evaluation of evacuation behavior in networks under disaster situations.

The time from the moment when disaster occurs to the evacuation complete time varies greatly depending on the types of disaster. If the time is not so short, people tend to think that there is enough time and choose to evacuate only after conducting activities other than evacuation. For example, in the Great East Japan Earthquake that caused great damage in Japan in 2011, there was a delay of about 40 minutes before the arrival of the tsunami in some area. The results of our survey shows that although it covers only survivors, over 30 % of them chose activities in danger zones before evacuation. As for the victims, lager proportion of people may have chosen activities in danger and suffered from tsunami. In order to analyze evacuation behaviors, it is necessary to describe the risk perception of the completion time of each evacuation performed by each individual and recognition about planning for the future.

Therefore, in this research, we suggested a model based on discrete-continuous model which explicitly handles constraint time and considers sequentially selection of activity type which is discrete variable and time allocation which is continuous variable at the same time.

2 Model Framework

Based on Habib(2011)'s model[1], we expanded A conventional static discrete-continuous model to a format that can deal with dynamic scheduling problems by incorporating time discount rate (Bellman, 1957[2])for discrete choice. Time discount rate reflects how organized the scheduling is under circumstances requiring evacuation. We also considered that time constraint perception is different for each individual depending on the characteristics of personal preference or geographical surrounding conditions. Heterogeneity of time constraints reflects differences in risk perception.

We derive the selection probability by assuming the Markov process for the utility function of discrete selection. In addition, the utility function of continuous selection is derived considering both the allocation time to the current activity and the allocation time to all future synthesis activities, and the Kuhn Tucker optimization condition under the constraint time condition Apply. For each of these selection probabilities,

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i.i.d. Gumbel distribution is assumed and its marginal probability is converted by an inverse function of the standard normal distribution. As a result, the simultaneous selection probability according to the bivariate normal distribution having the correlation by the converted two standard normal distributions is obtained.

When individuals realize the occurrence of the disaster, they decide whether to evacuate considering the risk and utility of future activity. At the same time, they decide how long time they should take for each of the just selected activity and how long time should be left for later. They sequentially repeat this process until the "time limit", the moment they think that they can act safely. This result is scheduling of each individual.

It can be used as a evacuation planning method in advance.

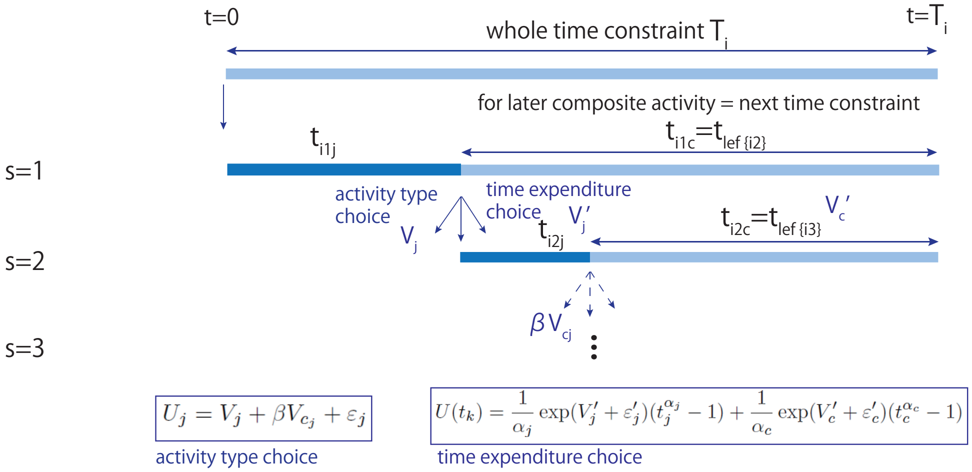

Figure 1: Dynamic descrete-continuous choice model incorporating heterogeneity of time constraint

We assumed utility function and time constraint as below. Let us suppress the subscript i for the utility function of the individual i.

Discrete Choice

$$U_j = V_j + \beta V_{c_j} + \varepsilon_j \tag{1}$$

$$\tag{2}$$

where V is the systematic utility of activity type choice for the chosen activity (j) and future activity altenatives (c_j). β is time discount rate. ε_j is the unobsevable random error term.

Continuous Choice

$$U(t_k) = \frac{1}{\alpha_j}\exp(V_j' + \varepsilon_j')(t_j^{\alpha_j} - 1) + \frac{1}{\alpha_c}\exp(V_c' + \varepsilon_c')(t_c^{\alpha_c} - 1) \tag{3}$$

where t is the time expenditure, α is the satiation parameter, V' is the systematic utility of time expenditure choice and ε' is the unobsevable random error term for the chosen activity (j) and future composite activities (c).

Time Constraint

$$T_i = f(social_i, geo_i) \tag{4}$$

$$t_j + t_c = T_i^j \tag{5}$$

$$T_i = \sum t_j \tag{6}$$

Under these constraints, the joint probability of discrete and continuous choice is led by using an inverse of the cumulative standard normal variable (Ψ^{-1}). Based on the joint probability, the likelihood function (L_i) can be written as:

$$\begin{aligned} L_i = \prod_{j=1}^{n} \Big(\big(\frac{1-\alpha_{ji}}{t_{ji}} + \frac{1-\alpha_{ci}}{t_{ci}} \big) \frac{1}{\sigma} \exp\big(\frac{-(V'_{ci} - V'_{ji})}{\sigma} \big) \big[1 + \exp \frac{-(V'_{ci} - V'_{ji})}{\sigma} \big]^{-2} \\ \times \Phi\big(\frac{J_1(\varepsilon_{ji}) - \rho_{jt} J_2(\varepsilon'_{ji})}{\sqrt{1-\rho_{jt}^2}} \big) \Big)^{D_{ji}} \end{aligned} \tag{7}$$

such that

$$J_1(\varepsilon_j) = \Phi^{-1}\big[(\varepsilon_n - \varepsilon_j) < (V_j - V_n) \big] \tag{8}$$

$$J_2(\varepsilon'_j) = \Phi^{-1}\big[(\varepsilon'_j - \varepsilon'_c) < (V'_j - V'_c) \big] \tag{9}$$

where ρ is correlation and σ is a scale parameter.

3 Case Study and Conclusion

We estimated parameters as a case study using survey data about the Great East Japan Earthquake in 2011 and the reproducibility of the model was confirmed. We conducted the survey in Rikuzentakata-city, Iwate Prefecture, Japan. In the Great East Japan Earthquake, the cause of the death of 90 % of the victims was drowning and the arrival time of tsunami was about 40 minutes later than the occurrence of the first earthquake.

In this case study, the primary Markov process was assumed. That is, we assumed that activity type was selected after considering the activity selection one step ahead.

Table 1 is a result of estimation. This shows some of tendency under evacuation circumstances.

Firstly, elderly people are more likely to choose evacuation and time assigned to evacuation is short. Therefore, in an aging society, the usefulness of a tsunami evacuation tower that does not require long-term travel for evacuation is expected.

Secondly, we found that evacuation decision is not organized enough. Our research showed that time discount rate for discrete choice is small. That is, the planning is unreasonable because the future utility can be often ignored and decision making is done ad hoc.

Finally, according to the value of the explanation parameter related to the time constraint, there is a big difference in behavior scheduling between high risk area and low risk area. If at the time of occurrence of the earthquake individuals are close to the coast, where tsunami arrival is fast, they are more likely to consider time constraint is short. So they tend to start evacuation immediately. However,if they are far from the coast, they judge time constraint is long maybe because the moment of tsunami arrival is often later than that in the area close to the coast. It seems natural that time constraint which individuals recognize depends on geographical place, but it can be a serious problem. Traffic demand for evacuation from 2 area(an area close to sea and one far from sea) may overlap near the shelter. This tendency can cause serious congestion and lead a lot of people into failure of evacuation before arrival of danger, tsunami.

We contracted Rikuzentakata city to a liner city (Fig. 2) and then calculated virtual evacuation flow and the delay time due to congestion. The result is shown in Fig. 3. It revealed that the link 1, which is near the shelter, was crowded in the later time zone in case of present condition (i). In the preliminary reconstruction plan, it is usually considered safe to relocate cities so as to lengthen the distance from the coast of the urban area. However, because of cognitive tendency about a time constraint based on sea distance, in fact congestion may occur and people may fail to evacuate by the time of danger arrival. Evacuation will not succeed simply by emigrating to a safe area.

In evacuation network planning, it is necessary to strategically plan the capacity allocation of transportation network, especially in areas where car evacuation is necessary. Or, by conducting disaster prevention education in advance (case (ii) in Fig. 3), it may be possible to change such constraint time perception and ask individuals to evacuate as immediately, regardless of the distance from the coast. It reduced the delay time due to congestion.

Analysis of such evacuation behavior and management of traffic flow based on that mechanism were shown to be indispensable. By using the model of this research, it is possible to evaluate each case reflecting the change of various factors of the assumed disaster scenario, such as change of social composition, education, urban structure change.

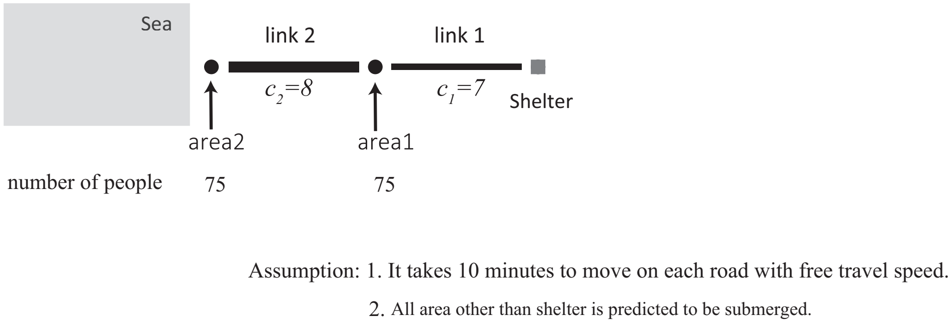

Figure 2: Contract of Rikuzentakata city

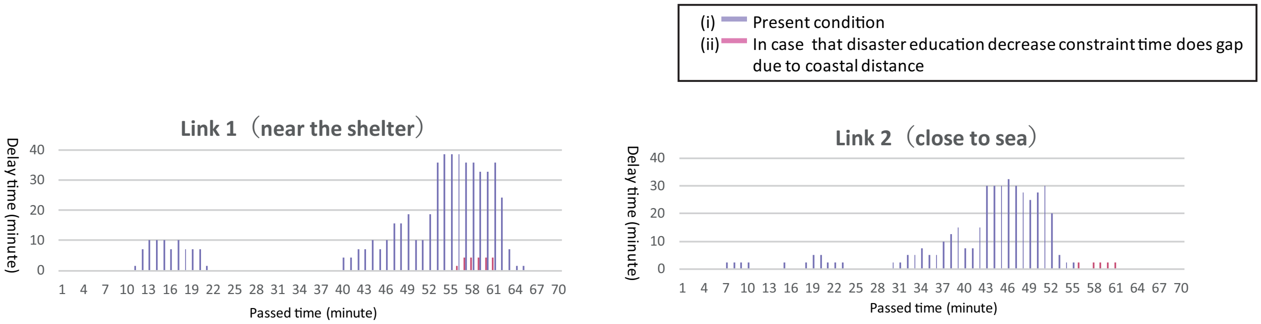

Figure 3: Delay time due to congestion by time zone

References

[1] Khandker M. Nurul Habib. A random utility maximization (RUM) based dynamic activity scheduling model: Application in weekend activity scheduling. *Transportation*, 38(1):123–151, 2011.

[2] Bellman Richard. Dynamic programming. *Princeton University Press*, 89:92, 1957.

Table 1: Estimation result

		case 1		case 2		case 3	
time discount rateβ		as a parameter		0		0.5	
explanation variables		parameter	t-value	parameter	t-value	parameter	t-value
time expenditure choiceψ							
V'_j baseline utility							
evacuation							
man dummy		-0.432	-0.974	-0.239	-0.587	-0.462	-1.040
aged dummy		-0.979	-2.094	-0.772	-1.914	-0.985	-2.120
car use dummy		0.459	1.202	0.416	1.156	0.500	1.317
sea distance(*1)		-1.075	-0.766	-0.329	-0.268	-1.111	-0.782
other activities							
degree of "for other"		0.885	1.042	1.108	1.395	0.757	0.889
constant		-0.481	-1.080	-2.703	-1.944	-0.470	-1.044
common							
area dummy	1	-0.445	-0.604	1.424	1.324	-0.461	-0.632
	2	1.000	NaN	1.000	NaN	1.000	1.272E+14
	3	0.660	NaN	0.423	5.601E+09	0.512	NaN
	4	1.000	3.285E+10	1.000	NaN	1.000	NaN
	5	0.693	2.497E+10	0.615	NaN	0.023	4.438E+12
	6	1.000	NaN	1.000	1.756E+10	1.000	1.075E+15
	7	0.225	NaN	0.937	NaN	0.448	NaN
	8	1.000	3.851E+10	1.000	NaN	1.000	NaN
V'_c baseline utility							
evacuation							
man dummy		-0.562	-1.110	-0.782	-1.563	-0.551	-1.086
aged dummy		0.275	0.533	-0.187	-0.382	0.304	0.587
car use dummy		-0.173	-0.377	-0.273	-0.597	-0.199	-0.433
sea distance(*1)		0.398	0.200	-2.220	-1.303	0.470	0.232
other activities							
degree of "for other"		-1.194	-1.009	-0.154	-0.138	-1.202	-1.006
constant		1.367	2.326	1.000	6.713E+10	1.398	2.262
common							
area dummy	1	0.836	1.333	0.130	0.219	0.858	1.357
	2	0.534	0.990	-0.137	-0.293	0.530	0.968
	3	0.256	0.468	-0.274	-0.549	0.263	0.473
	4	0.605	1.563	0.275	0.780	0.613	1.571
	5	0.639	1.242	0.165	0.373	0.651	1.253
	6	-0.317	-0.372	-0.361	-0.422	-0.297	-0.347
	7	-0.343	-0.264	0.223	0.162	-0.354	-0.269
	8	-0.017	-0.025	0.074	0.116	-0.025	-0.037
satiation parameter(*2)	α_j	-0.575	-11.779	-0.559	-11.491	-0.573	-11.587
	α_c	0.539	NaN	0.958	NaN	0.306	1.289
activity choice γ							
evacuation							
man dummy		-2.027	-4.610	-4.915	-11.322	-2.125	-4.623
aged dummy		0.177	0.407	-2.340	-5.058	-0.057	-0.129
car use dummy		48.060	2.474	63.443	1.187	68.705	5.515E+06
sea distance(*1)		-1.721	-1.181	-17.561	-8.729	-2.216	-1.440
other activities							
degree of "for other"		-19.935	-18.338	-15.937	-18.789	-20.766	-20.400
area dummy	1	-8.142	-11.988	35.577	2.488E+05	-8.645	-13.107
	2	-10.541	-10.767	-8.095	-11.239	-11.222	-11.314
	3	-10.868	-11.259	-10.771	-8.462	-11.428	-12.064
	4	-6.850	-10.284	-9.980	-8.487	-7.550	-12.436
	5	-9.959	-11.627	-6.367	-8.649	-10.669	-13.258
	6	-11.836	-7.687	-9.685	-10.046	-12.812	-7.081
	7	-12.483	-8.148	-23.894	-1.438	-13.049	-8.210
	8	-10.004	-10.720	-12.654	-6.291	-10.702	-11.188
constant		6.719	13.314	0.400	9.079	6.837	13.107
time discount rateβ		0.579	12.352				
correlation coefficientρ(*2)		-0.237	-1.977	-8.900	-7.934	-0.263	-2.255
time constraint τ(*3)							
man dummy		7.354	NaN	-0.145	-1.246	0.888	0.552
aged dummy		7.960	NaN	4.761	NaN	0.966	0.549
sea distance(*1)		4.471	NaN	8.534	NaN	0.572	0.401
constant		4.721	NaN	13.892	NaN	0.803	0.791
initial likelihood		-2448.550		-2448.550		-2448.550	
final likelihood		-1826.531		-1923.997		-1827.767	
likelyhood ratio		0.254		0.214		0.254	
modified likelihood ratio		0.234		0.194		0.234	

*1 unit: 10000 m
2 Each parameter b must satisfy $0 < b \leq 1$, so the value on this tab is a that is represented $b = 1 - \exp(a)$.
3 unit: 1000 minutes
4 It did not converge within 100 iterations of the BFGS method, and the parameter is that obtained at the final stage.
5 The t value was derived using the Moore-Penrose type generalization inverse matrix.