Influence of Family Safety Information Availability and Shelter Conditions on the Behaviour of Earthquake Stranded Commuters: A Multi-Agent Simulation Analysis

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Abstract
This paper proposes a model that clarifies the influence of family safety information levels and shelter conditions on the behaviour of earthquake stranded commuters. The model is based on Multi-Agent Simulation (MAS) framework so as to capture the interactions among commuters and its influence on personal decisions. Simulation experiments were carried out with the purpose of demonstrating the model. These experiments are based on a hypothetical earthquake in the city of Sapporo, Japan, where earthquakes are common weather phenomena. Model outputs highlight the importance of family information and perceived shelter environment conditions on commuters' decision-making towards staying at safe shelters or facing uncertain returning-home journeys. Simulation outputs also identify the importance of sojourn shelters in reducing the likely hazards posed to stranded travellers. Furthermore, the results of an original path choice algorithm, proposed in this study, indicate that *enroute* road choice changes are performed by travellers due to road conditions.

Keywords: Stranded Commuters; Earthquake; Family Information; Shelter Conditions; Multi-Agent Simulation

1. INTRODUCTION

Severe natural disasters such as earthquakes damage living environments, while posing hazards to humans. Large numbers of stranded commuters are commonly observed after the occurrence of such disasters due to suspended operation of public transportation. A report by Mitsubishi Research Institute (MRI, 2011) highlighted that 2.6 million people in Tokyo metropolitan area faced difficulties returning home after the Great East Japan Earthquake on March, 2011. Cities around Japan have released estimates on expected numbers of stranded travellers in the occurrence of earthquakes as these are a constant threat to the country. Sapporo emergency management office announced in its Third Earthquake Damage Assessment report that a large-scale earthquake would strand 44 thousand travellers during the summer, while this figure would rise to 83 thousand travellers during the winter (City of Sapporo, 2012).

Stranded commuters face challenging scenarios and decisions. In the occurrence of severe weather phenomena, these commuters are likely to face the decision of staying at shelters or advancing towards their households. However, such decisions turn to be highly complex as human behaviour under severe weather conditions is influenced by numerous factors, including fear about the current situation of families, shelter safety and comfort conditions, availability of public transportation, and road network information (Yazici and Ozbay, 2007; Riad *et al.*, 1999; Pel *et al.*, 2011). Another complicating factor is the increasing mobility difficulty during evacuations due to the faster growth of urban populations than the parallel growth in road infrastructure and transportation capacity (Barret and Pillai, 2000; Plowman, 2001). Accordingly, commuters often attempt to walk home in such events, as a result of unavailability of public transportation and uncertainty about road network conditions. Moreover, it is broadly recognised that the decision of surrounding commuters may influence personal decisions (Kukla *et al.*, 2001; Mawson, 2005; Dombroski *et al.*, 2006), which further contributes to the complex decision-making under risky conditions.

Anticipating human behavioural patterns in weather phenomena is fundamental for emergency management teams (Zhan and Chen, 2008). Efforts have been made towards further understanding commuters' behaviour in such risky environments. Kagaya et al. (Kagaya *et al.*, 2011) used Multi-Agent Simulation (MAS) to investigate returning home behaviour of stranded travellers. This study suggested that travellers tend to return home as soon as possible after an earthquake outbreak. It also showed that information on public transportation directly affects travellers' behaviour. Geographic Information Systems (GIS) and MAS were used by Kagaya et al. (Kagaya *et al.*, 2005) to represent the influence of spatial changes due to an earthquake on post-earthquake behaviour. This study applied random utility theory to represent travellers' decision towards returning home or staying at a shelter. A detailed questionnaire survey among those commuters affected by the Great East Japan Earthquake identified personal conditions, family conditions and public transport conditions as most significant for stranded commuters (Yu *et al.*, 2011).

In this study a simulation model which expresses the influence of family safety information levels, as well as shelter environment conditions at school or company, on commuters' walking home behaviour in the occurrence of a large-scale earthquake is proposed. The model is based on MAS framework so as to capture the interactions among travellers and its influence on personal decisions. The study identifies potential factors towards reducing numbers of stranded commuters, as well as towards reducing dangers related to those commuters who decide to walk home. A simulation experiment based on a hypothetical earthquake in the city of Sapporo, Japan is performed. The hypothetical quake is assumed to occur at 6pm when most commuters are likely to return home. Simulation outputs suggest that even limited family safety information would have a positive impact on commuters' decision towards staying at safe shelters. Perceived comfort at shelters also appeared to influence commuters' decision towards walking home, staying at the current shelter or walking towards a sojourn shelter. The paper analyses the current status of shelter availability within the case study area. The analysis proposed in this study is highly important for evacuation management teams towards minimising the hazards posed to the population in the occurrence of earthquakes.

2. MULTI-AGENT SIMULATION APPROACH

MAS approach has emerged as a powerful technology for dealing with complex systems (Weiss, 1999; Wooldridge, 2009). It consists of an environment with multiple autonomous agents which have the ability to sense, perceive and take action, while interacting with of other agents (Teo *et al.*, 2012). MAS can enhance the analysis of problems that include a geographically distributed domain, dynamic subsystems, and flexibly interactive subsystems (agents) (Adler and Blue, 2002). Accordingly, MAS systems have been largely applied in a wide range fields, such as electronic commerce, network management, information management systems, and transportation engineering. A robust review of MAS applications in traffic and transportation systems is presented by Chen and Gheng (Chen and Cheng, 2010).

Disaster planning can also be benefited by MAS-based modelling. The complexity associated with disaster planning, particularly in urban environments, requires a flexible modelling framework that is capable of incorporating factors such as: the nature of the disaster, human behavioural patterns under risky conditions, population distribution, and characteristics of the geography and transportation infrastructure of the affected areas (Zhan and Chen, 2008). Recent efforts towards developing MAS simulations for disaster planning ratify its effectiveness in disaster planning, crisis management and emergency response (Murakami *et al.*, 2002; Massaguer *et al.*, 2006; Jain and McLean, 2008). Our study contributes to the literature by developing a MAS model to investigate the influence of highly significant factors, i.e. family safety information and shelter conditions, on the behaviour of stranded commuters.

3. MODELLING FRAMEWORK

The simulation performed in this study hypothesizes the occurrence of a large-scale earthquake in the city of Sapporo, Japan, at 6pm on a weekday. At this time, most employees and students are expected to return home after their working day. Details on the modelling framework are described in this section.

3.1 Multi-Agent Simulation Model

The MAS model developed in this study simulates commuters' returning home behaviour on the occurrence of a hypothetical large-scale earthquake. Data collected through questionnaire surveys, combined with Person Trip (PT) survey data, are used to create basic modelling rules. The flowchart of the MAS model is shown in Figure 1. Initially, commuters' decision towards "staying at current shelter" or "returning home", immediately after an earthquake occurrence and under certain conditions, is modelled. Shelter is defined as a company or school where commuters are likely to be at the time of the hypothesized earthquake. The returning home behaviour model is based on Random Utility Theory and developed in the form a Binomial Logit model. It is hypothesized in this research that if the decision involves family information availability, particularly when combined with shelter conditions, the commuter may take a decision based on utility maximization. Social attachment, i.e. the presence of familiar figures or the knowledge about their conditions, has been suggested as an influent factor in individuals' behaviour during disaster conditions (Mawson, 2005). Accordingly, it can be expected that commuters will try to maximize the benefits (or the utility) related to their decision, even though it may be an unconscious behaviour.

Random Utility Theory suggests that choice preferences towards a certain alternative can be shown through its utility. Also, it is assumed that the alternative with the highest utility is chosen by the decision maker (Meyer and Miller, 2001; Bierlaire, 2011). The utility of a certain alternative is composed by observed and unobserved (random) terms. The observed term of the utility includes a set of observed variables related to the alternative and the decision maker; and a vector of alternative coefficients. The random term includes the uncertainties related to the analyst's limited information on individual preferences (Ben-Akiva and Lerman, 1985; Ortuzar and Willumsen, 2001).

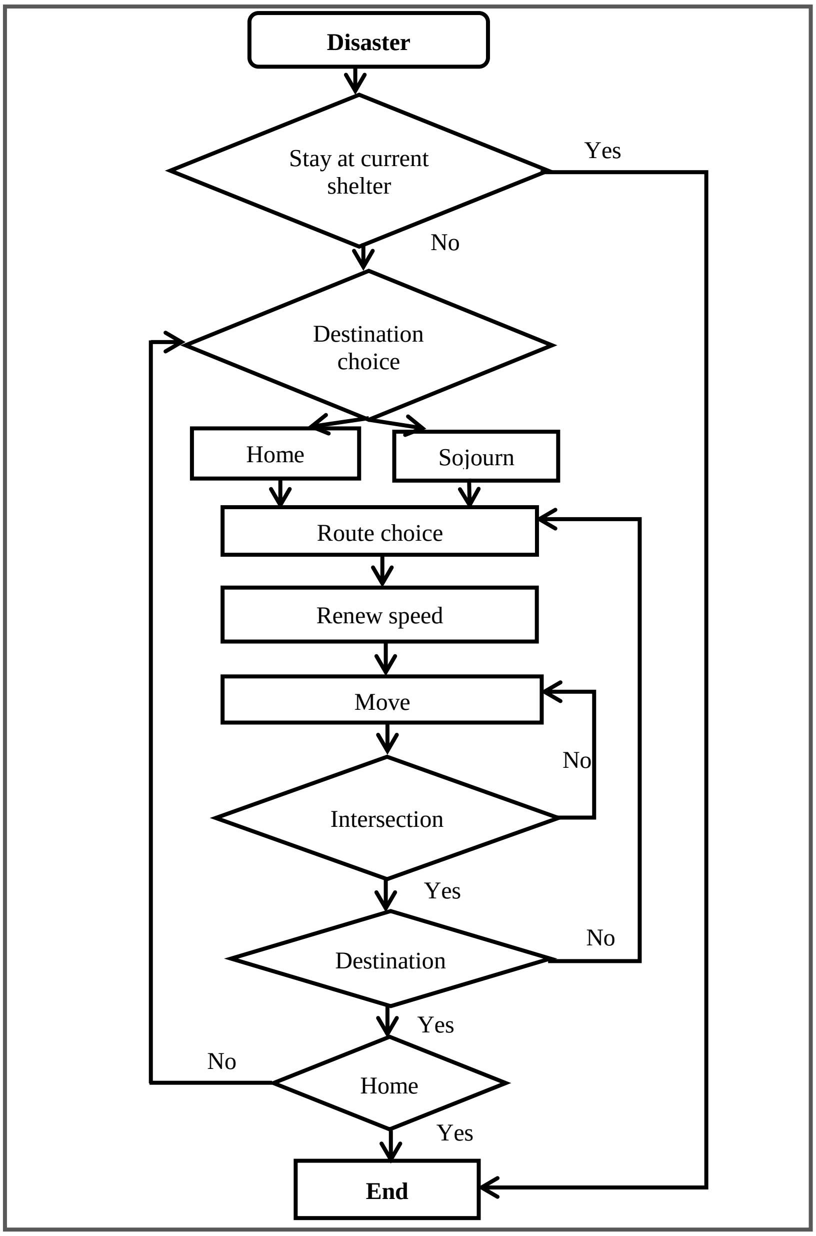


Figure 1. Flowchart of commuters' returning home

In this study, attributes related to season, walking home time, availability of family safety information and shelter environment conditions are investigated as explanatory variables. The utility function of returning home in the case of an earthquake and its respective choice probability are calculated by Equations 1 and 2, respectively. In these equations, x_{ik}: explanatory variables, i.e. season (1 if summer, 0 if winter), walking home time (minutes), family safety information check (1 if checked, 0 otherwise), shelter environment conditions (1 if good, 0 otherwise); β_{ik}: attribute variable parameters; and α: constant term of utility. Good environment at shelter is assumed if daily basic needs (e.g. light, heating, water, food and blankets) are available for a 2 days period. It was also assumed that shelter is available for the number of commuters present at the company or school on time of the hypothesized earthquake. Consequently, shelter capacity was not included in the current analysis.

$$\Delta V_i = \alpha + \sum_{k=1}^{k} \beta_{ik} . x_{ik} \tag{1}$$

$$P[go] = \frac{1}{1 + e^{-\Delta V}} \tag{2}$$

After modelling commuters' behaviour towards returning home or staying, simulation of returning home movement takes place. Movements from downtown towards two residential districts are simulated. A destination choice takes place between returning home directly and moving towards a sojourn shelter. The agent (commuter) then moves towards the following road intersection. For each road intersection, commuters' routing decision and speed information are repeatedly updated until they reach the destination point. The actual node-link road network is used in the simulation. Road damage levels are assumed to influence road congestion levels, thus are taken into consideration.

The Shortest Path choice algorithm is used to simulate the route choice behaviour of the commuter who is familiar with available routes home. The effects of congestion and link's damage due to earthquake on walking time are taken into account in the simulation as will be shown later. Furthermore, an original path choice algorithm is proposed in this study to deal with the commuter who is not familiar with available routes. The algorithm is based on both the angle between a nearby road intersection and the destination point at each intersection, and the numbers of people approaching the nearby intersection. Intersection choice is made based on choice probabilities described as follows:

$$u_i = \alpha \cdot ln\left(\frac{|cos\theta_i|}{\sum_{j=1}^{n} |cos\theta_j|}\right) + \beta \cdot ln\left(\frac{N_i}{\sum_{j=1}^{n} N_j}\right) \tag{3}$$

$$P_i = \frac{exp(u_i)}{\sum_{j=1}^{n} exp(u_j)} \tag{4}$$

In these equations, u_i: utility of i^{th} intersection; n: number of available intersections; α: utility coefficient for angle; β: utility coefficient for number of people; N_i: number of people approaching to i^{th} intersection; θ_i: angle between i^{th} intersection and destination point; P_i: probability of i^{th} intersection being chosen. Additionally, roads may become dangerous due to the number of people trying to return home. The probability shown by (4) means that the smaller the angle θ_i is, the larger the probability P_i is, and that the larger the number of people N_i is, the larger the probability P_i is. Especially, the second term of right hand side of (3) reproduces the route choice behaviour under uncertain situation, i.e. under the occurrence of a disaster, in which the commuter who is not familiar with the available routes is likely to approach to a nearby intersection to which many commuters are approaching. If there is no commuter proceeding to all nearby intersections, intersection choice is made based only on the angles since the second term of (3) equals 0. A nearby intersection (i) to which no commuter approaches will never be chosen if the other nearby intersection(s) to which commuters approach since $u_i = -\infty$. Cases where commuters decide to make a sojourn stay before advancing their returning home route were also simulated.

Besides the uncertain behaviour within the route choice decision, uncertainty is taken into account from the initial stage of the modelling process. MAS models consider the interaction among commuters within the decision process, which contributes to the uncertain decision making under risky conditions. Thus, uncertainty is input to the MAS model rules in the simulation process.

3.2 Case Study Area within Sapporo City

Information from commuters in the city of Sapporo was used for modelling and simulation purposes. Large numbers of commuters in Sapporo are expected to be stranded in the occurrence of a large-scale earthquake (City of Sapporo, 2012). Sapporo is the capital and the biggest city in the northern Japanese island of Hokkaido. The city has a population of 1.9 million, from which approximately 45% is a working population. It represents 1.5% of Japan's population and 34.8% of Hokkaido's population (Sapporo City, 2011). With a regional and an international airport, one of the biggest universities in Japan (Hokkaido University) plus several private universities, and substantial shopping centres, the city is the major economic centre in the region.

Downtown Sapporo includes Sapporo station, Odori station and Susukino station areas (highlighted in Figure 2), which compose the commercial hub of the city. The Central ward, along with the North and East wards (Figure 3(a)) generate big numbers of trips daily. In average, these wards generate 4 million trips per day, which accounts for approximately 36% of the total daily number of trips generated within Sapporo metropolitan area (Sapporo City, 2012).

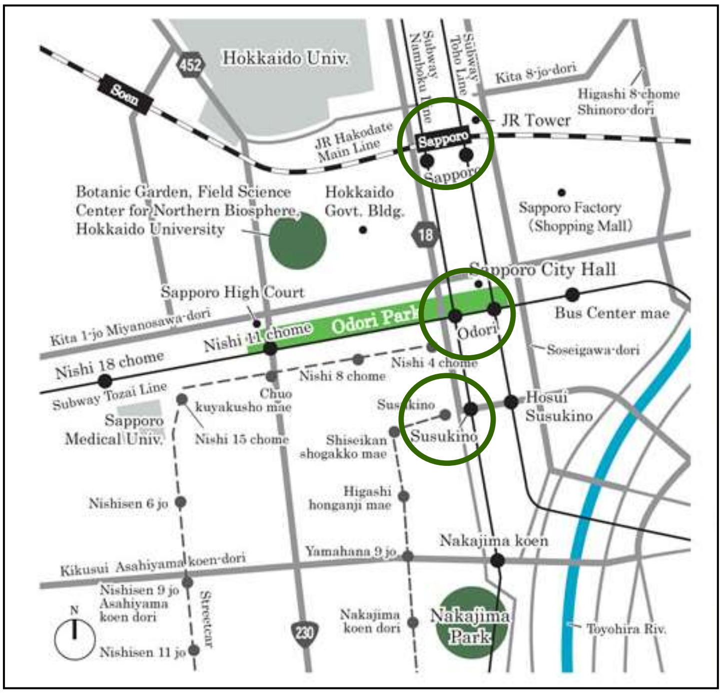
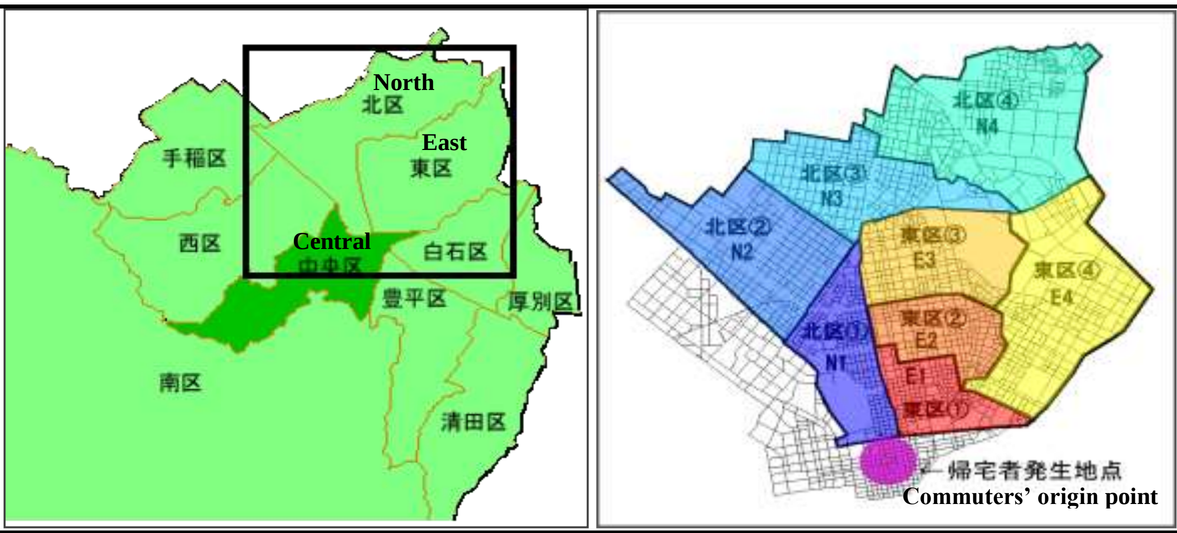


Figure 2. Map of downtown Sapporo
http://www.sapporo-park.or.jp/odori/

The North and East wards are predominantly residential. It is then expected that large numbers of commuters will attempt to move from the Central ward towards these two residential wards in the occurrence of a large-scale earthquake. Accordingly, commuters' movements from the Central ward towards the North and East wards are simulated in this study. Figure 3(b) shows the assumed origin point and destination zones (divided into PT zones).



(a) Wards within Sapporo (b) PT zones within North and East wards

Figure 3. Details of the case study areas within Sapporo

3.3 Data Bases

Data from different data sets was combined to provide the necessary information for the analysis of the returning home decision behaviour and simulation stages in this study (Sections 4.1 and 4.2). Commuters' attributes of age, gender, average walking speed, household location, expected walking home time, preferred returning home routes, likely personal location at the occurrence of an earthquake (assumed at 6pm on a weekday) were required.

Initially, data from the Sapporo PT survey (Sapporo DfT, 2006) was used to estimate the number of people moving from the Central ward towards the North and East wards at 6pm on a weekday. Each of the destination wards is divided into four PT zones as shown in Figure 3(b). Then, information from the Basic Resident Register of Sapporo was used to collect residents' information within these zones. Finally, results of two questionnaire surveys carried out in December 2005 and December 2008 provided further information on individual attributes and household characteristics of commuters. These surveys looked at travellers' behaviours under disaster conditions within different seasons (Kagaya *et al.*, 2005; Kagaya *et al.*, 2011). Particularly, data from Kagaya *et al.* (2011) study was used to estimate the Returning Home Decision Behaviour model (see model outputs on Table 5). Commuters are defined as employees and students, 10 to 75 years old, who work or study in the Central ward. The final samples included the responses of 452 and 348 individuals, which represented 45.2% and 34.8% of response rates. While a priori knowledge about the range of responses is required in order to define the appropriate sample size for the analysis, disaggregate behavioural models do not require a large number of samples to ensure acceptable error to the estimation results (JSCE, 1995).

A summary of the above mentioned information is described in the following tables and figure. Table 1 describes the general characteristics of the sample by PT survey zones. Table 2 gives further details on the sample by age and gender. Figure 4 shows the road network of the study area and residential site distribution assumed in the simulation. Residential sites were determined on the basis of PT survey zones combined with number of people per small residential areas. Small residential areas are defined by the Town Planning Centre of Sapporo. Furthermore, information on the average walking speed is shown in the following section (Table 3).

Table 1. Characteristics of the data sample

PT Survey Zones	Travellers			Total Population	Number of Residential Sites
	Commuters	Shoppers	Others		
E1	6,111	1,168	743	53,341	42
E2	11,771	2,109	1,338	94,618	74
E3	8,478	1,750	908	57,207	45
E4	6,905	1,207	536	48,883	39
N1	10,904	2,815	1,717	72,025	52
N2	10,204	621	1,093	86,116	62
N3	6,510	508	1,000	53,895	39
N4	9,578	1,048	976	64,796	47

Table 2. Population distribution by age and gender

Age	Total Population (%)	Male (%)	Female (%)
10-14	5.4	50.9	49.1
15-19	5.8	50.3	49.7
20-24	7.1	49.1	50.9
25-29	8.1	47.6	52.4
30-34	8.9	48.4	51.6
35-39	10.3	48.6	51.4
40-44	9.7	48.3	51.7
45-49	8.6	47.3	52.7
50-54	8.7	47.4	52.6
55-59	9.5	47.5	52.5
60-64	6.3	47.1	52.9
65-69	4.4	45.9	54.1
70-74	3.9	44.1	55.9
75-79	3.3	42.0	58.0

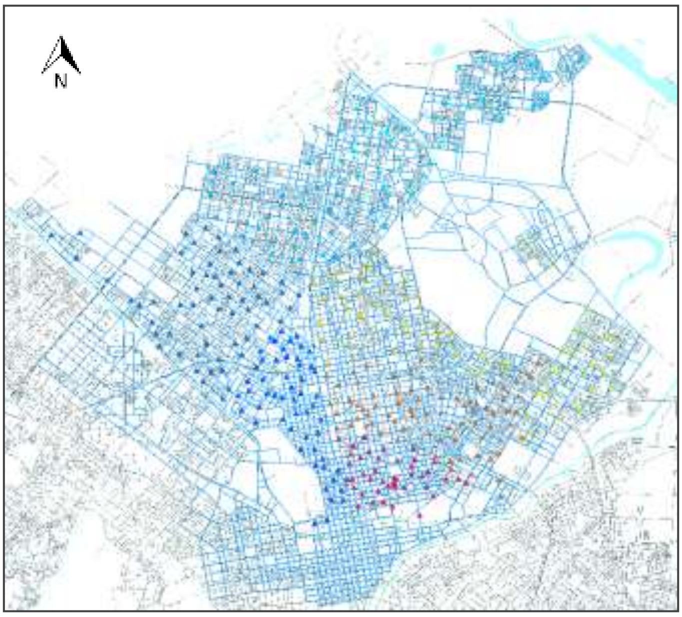


Figure 4. Road network and residential sites

3.4 Walking Speed Calculation

The walking speed used in the simulation is disaggregated by age and gender and is assumed to follow a normal distribution with mean and variance (Table 3). Congestion effect is also taken into account in calculating the walking speed. A liquefaction level and the corresponding speed reduction rate are equipped to each link in the road network, i.e. high (0.65), medium (0.85), low (0.95), and none (1), according to Sapporo Emergency Management Office (City of Sapporo, 2012). Therefore, the walking speed in the simulation reflects both congestion and liquefaction after the earthquake.

Table 3. Walking speed calculations

Congestion level ρ (person/sqm)	Walking speed (metre/minute) (Si: Sampled walking speed from normal distribution)
$\rho < 0.7$	Si
$0.7 < \rho < 4$	Si – ((Si – 24) / 3.3)*(ρ – 0.7)
$\rho > 4$	((24*4) / ρ

Age	Male walking speed (metre/minute)		Female walking speed (metre/minute)	
	Average	Variance	Average	Variance
10-14	46.2	5.9	56.0	4.9
15-19	64.4	6.4	50.4	3.9
20-24	61.6	4.9	51.8	5.9
25-29	59.5	5.4	51.8	3.9
30-34	59.5	6.9	50.4	3.4
35-39	59.5	5.9	47.6	4.4
40-44	57.4	4.9	47.6	4.4
45-49	57.4	5.9	47.6	6.9
50-54	54.6	5.9	47.6	4.9
55-59	50.4	4.9	44.8	2.5
60-64	49.0	4.9	42.0	3.9
65-69	44.8	2.9	42.0	3.9
70-74	42.0	2.9	38.5	2.9
75-79	38.5	2.5	35.0	2.5

3.5 Simulation Scenarios

The simulation scenarios set for this study were based on the conditions that an earthquake occurs in Sapporo city at 6pm on a weekday. Under these conditions, the number of stranded commuters is expected to reach its maximum level. These scenarios were drawn based on different levels of family safety information, both immediately after the earthquake occurrence and one hour after the earthquake occurrence; and shelter environment conditions. Seven simulation scenarios were tested, as detailed in Table 4, while a total of 100 simulation trials were performed for each scenario. Family Safety Information (FSI, immediately after the earthquake) was assumed as 0% (no information), 39% or 100%. Family Safety Information at Shelter (FSI 1 hour after the earthquake) was assumed as 0%, 50% or 100%. Moreover, Favorable Shelter Environment (FSE) rates were defined as 0%, 50% or 100%.

For the Current scenario, rates of family safety information immediately after the disaster and an hour later (on the time of a reevaluation of whether to return home or not) were adopted from the results of a questionnaire survey which was carried out after the East Japan Earthquake in March 2011 (Yu *et al.*, 2011). For scenarios 1, 4 and 5, which focus on family information availability, the rate of favorable shelter environment was assumed as medium (i.e. 50%). Scenario 1 is set as the base case and used as the comparison case in the analysis.

Although the traveller's behaviour choice probabilities are calculated based on the models mentioned earlier, the traveller's behaviour in the simulation is determined based on a random sampling r which is drawn from the uniform distribution, i.e. Uni(0,1), in a way that an alternative i is selected if $r \leq P_i$ $(\mathrm{i} = 1)$ or $P_{i-1} < r \leq P_{i-1} + P_i$ $(i \geq 2)$. Therefore, the results from the simulation will be shown in averages. In Equation 3, we assumed that $\alpha = \beta = 1$ and that the ratio of people who were not familiar with the available routes home was 50%. However, the rate of people who are not familiar with the available routes home in the simulation is determined based on a random sampling from Uni(0,1), as described above.

Table 4. Description of simulation scenarios

Variables	Scenarios						
	1 Current	2 USE	3 FSE	4 USI	5 ASI	6 Worst	7 Best
Family Safety Information (FSI immediate, %)	39	39	39	0	100	0	100
Family Safety Information at shelter (FSI 1 hour later, %)	50	50	50	0	100	0	100
Favorable Shelter Environment (FSE, %)	50	0	100	50	50	0	100

Scenario Description:
1. Current: Current status
2. USE: Unfavorable Shelter Environment
3. FSE: Favorable Shelter Environment
4. USI: Unavailability of family safety information
5. ASI: Availability of family safety information
6. Worst: Worst scenario (neither family information nor favorable environment)
7. Best: Best scenario (100% rates of safety information and favorable environment)

4. RESULTS AND DISCUSSION

Returning home decision behaviour, simulation outputs and analysis of the location of shelters are discussed in this section.

4.1 Returning Home Decision Behaviour

Probabilities of returning home based on season, walking-home time, family safety information check and shelter environment conditions (as further detailed in Section 3.1) are illustrated in Figure 5, while model output parameters are summarised in Table 5. Model parameters show that all attribute variables are highly significant to commuters when deciding whether to go home or staying. All parameters are sign-coherent and are statistically significant at the 0.99 confidence level (critical value is 2.58). Walking-home time parameter is negative, which is a sensible output. People are likely to stay at shelters in place of walking for long time, particularly if family safety check is performed and if environment at shelter is favorable. As shown in Figure 5, higher returning home rates are observed by the combination of unavailability of family information and unfavorable shelter environment.

The number of commuters moving from the Central ward to the North and East wards was estimated as 89,998 people. Their initial decision of either returning home or staying at the shelter was modelled by the previously described model (Section 3.1). The outputs of a questionnaire survey (Kagaya *et al.*, 2005) were then used to classify commuters by returning home: immediately after the earthquake occurrence or after a waiting period. Returning home rates are assumed as: immediately (42.1%); after 30 minutes (4.1%); after 1 hour (33.8%); after 2 hours (12.4%); and after 3 hours (7.6%). Commuters staying at working place or school are assumed to remain in the same place in case of good shelter environment. In case of unfavorable environment, half of those commuters are assumed to remain at the place and the other half is assumed to move toward sojourn shelters. A sojourn break was assumed for commuters who decided to walk home and remained walking for more than 1hour. A new judgment with regards to returning home (continue walking) or staying is then performed. A total of 97 schools or public buildings are identified as potential shelters within the study area.

Table 5. Outputs of the Returning Home Decision Model

Attribute	Parameter	t-statistics
Constant term	1.844	13.344
Season (summer)	0.656	7.057
Walking-home time (min)	-0.008	-10.560
Family safety inf. check (checked)	-0.495	-5.332
Shelter environment (good)	-1.146	-12.386
Summary of statistics (Kagaya *et al.*, 2011)		
Number of observations: 2328 (291 valid responses x 8 case scenarios)		
Likelihood ratio: 0.308		
Predictive ratio: 62.59%		

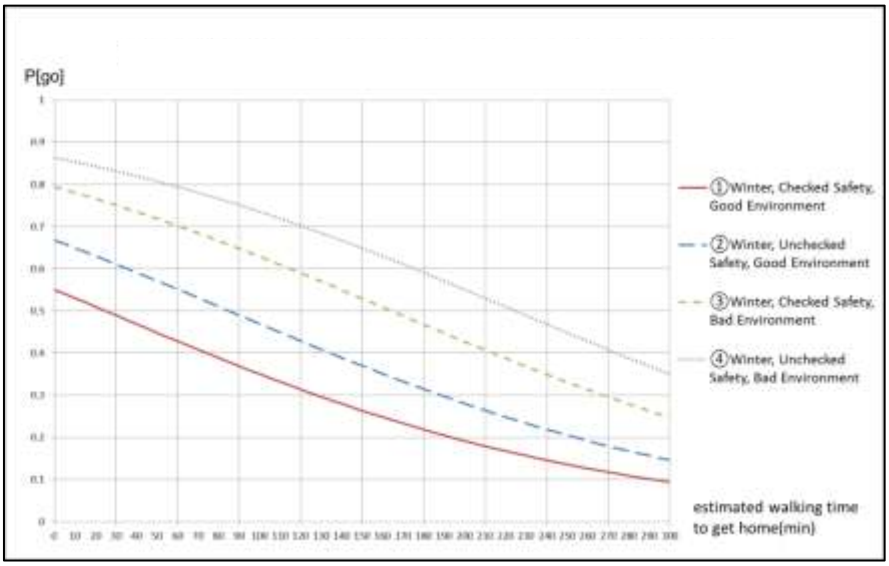


Figure 5. Commuters' returning home decision probabilities

Analysis of the returning home movement based on *enroute* conditions was also performed. This analysis represented the choice between returning home directly and moving towards a sojourn shelter. The proposed original path choice algorithm, suggest that the interaction among commuters influence choice behaviour. The algorithm indicated that commuters who are not familiar with available routes are more likely to approach intersections to which other commuters are approaching. Moreover, the Shortest Path choice algorithm took into consideration the effects of congestion and link's damage caused by an earthquake on walking time. However in the current study, these effects were inputs to the model, hence further research is planned so as to incorporate congestion and damage effects into the simulation model.

4.2 Discussion on the Simulation Outputs

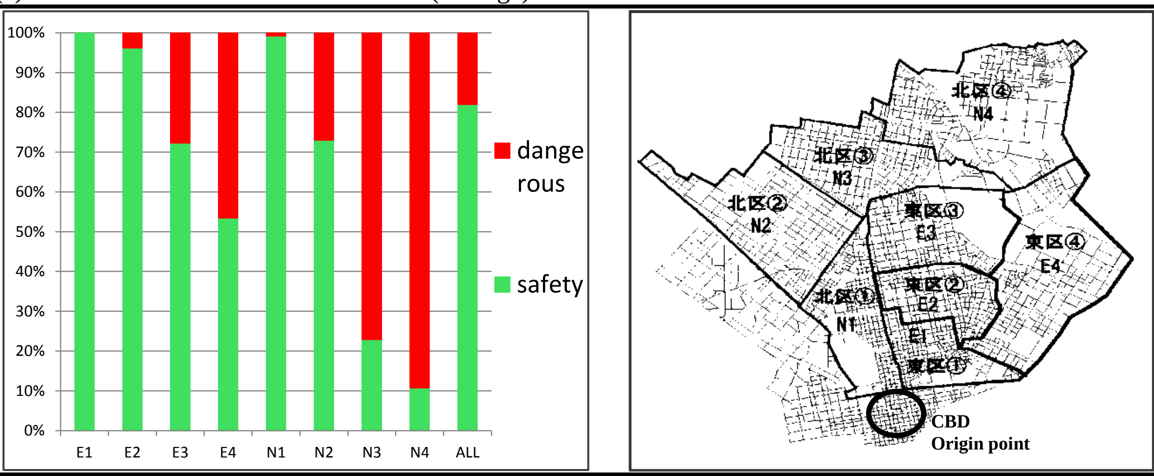
Initially, outputs from Scenario 1 were analysed. Scenario 1 is defined as the current status (base case), where FSI immediate (39%), FSI 1 hour later (50%) and FSE (50%). As shown in Figure 6(a), approximately 45% of commuters were estimated as having intention of returning home. From these, about 71% completed their return journey within 10hours after the earthquake occurrence. It is also shown that large numbers of commuters are expected to make sojourn breaks during their journey, as well as several stay at current shelters. These figures emphasise the importance of shelter availability throughout residential wards so as to support stranded commuters in completing their journey. Similarly, companies and schools are advised to be equipped with a 2-days' basic living supply.

Figure 6(b) shows the rates of return journeys classified between dangerous journeys and safe journeys. Journeys longer than 10 hours are assumed as dangerous. It is notable that zones which are further from the origin point include bigger numbers of dangerous journeys (Figure 6(c)). Particularly, zones N3 and N4 are indicated as dangerous zones to walk. Conversely, it is observed that zones near to the CDB include less or none dangerous journeys. 82% of safety rate was estimated for the entire area through this simulation.

Following, the simulation outputs from scenarios 2 to 7 were compared to those from Scenario 1, while taking into consideration different environment conditions and family safety information. These outputs are summarised in Table 6. Outputs from Scenarios 2 and 3 highlight that environment conditions at company or school directly influence the decision of returning home. Unfavorable shelter environment motivates people to return home immediately after an earthquake occurrence. However, it in turn reduces safety levels with larger numbers of unsafe journeys and lower safety ratio. Number of commuters returning home is considerably smaller in Scenario 3 than in Scenario 1. Accordingly, it is indicated tat favorable shelter environment induces commuters to stay, even if family safety information is limited. These outputs are sensible and suggest that the proposed simulation model is appropriate to represent the behaviour of stranded commuters.

Total No. Commuters	Return Home Intention	Journey Complete	Journey Incomplete	Sojourn	Stayed at Company or School	Safe Return	Unsafe Return
89,998	40,560	28,924	235	39,736	19,438	23,723	6,155

(a) Simulation of commuters' behaviour (average)



(b) Commuter returning home rates per zone (c) Study zones

Figure 6. Outputs of Scenario 1 (current status)

The model was also able to simulate commuters' behaviour under different family safety information levels. High level of family safety information indicated that less people will risk returning home immediately after an earthquake (Scenario 5). However, outputs from Scenario 5 are significantly similar to base case results, despite levels of family information being less in the later. This output suggests that even limited family safety information would have a positive impact on commuters' decision to stay at shelters. It is then suggested that in disaster occurrence, information systems are fundamental so as to reduce unsafe retuning home journeys. Scenarios 6 and 7 ratify the importance of family safety information and shelter environment conditions on safety levels in the occurrence of a natural disaster such as an earthquake.

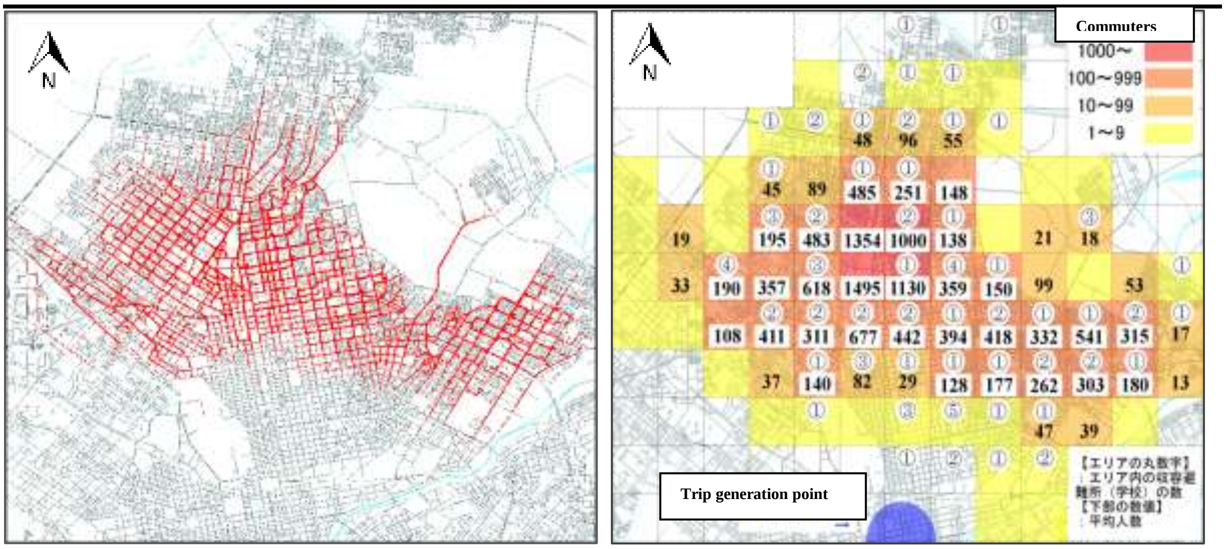
Table 6. Simulation outputs: All scenarios

Outputs		Scenarios						
		1 Current	2 USE	3 FSE	4 USI	5 ASI	6 Worst	7 Best
Return home decision (commuters)		40,560	49,542	31,564	50,609	40,554	59,828	31,474
Journey complete (commuters)	Safe	23,723	28,346	19,186	30,807	23,767	35,477	19,166
	Unsafe	5,201	6,465	3,706	7,090	5,161	8,885	3,710
Safety ratio (%)		82.0	81.4	83.8	81.3	82.2	80.0	83.8
Sojourn (commuters)		61,023	54,970	67,085	51,782	61,017	45,250	67,091

As discussed above, the attribute variables considered in this study are highly important to commuters when deciding whether to walk home or to stay in a safe shelter, thus avoiding dangerous journeys. Availability of family information and shelter conditions are likely to be among the paramount reasons influencing commuters' behaviour. Favorable shelter conditions includes a 2-days basic needs availability, which likely motivate people to stay, particularly when combined with family safety information availability. Future analysis should also include other factors not investigated in this study, such as road danger conditions caused by the occurrence of explosions or such; availability of government official guidance; and personal conditions, e.g. availability of appropriate clothes and footwear, or required medication.

4.3 Analysis of the Arrangement of Shelters

Scenario 1 was used to investigate levels of danger for commuters in case of no availability of shelters or sojourn places. For this simulation, all commuters were assumed to return home after the earthquake. Figure 7(a) illustrates the commuters' distribution after 3 hours of continuous walk. This figure highlights that numerous commuters would face difficulties reaching their destination, even after a long walking period. These commuters were grouped in 1sq km areas according to the location of their final destination, as detailed in Figure 7(b). The number of potential shelters in each area is also displayed. These shelters are either schools or public buildings, which are identified as appropriately located for shelter purposes. In most of these areas, at least one potential shelter was identified. However, shelters are not available within two of the central areas, where the biggest numbers of stranded commuters are identified (1,495 and 1,354 commuters). This map gives a clear view on the distribution of points where attention should be given by evacuation plans in the North and East wards of Sapporo city.



(a) Danger status plot

(b) Number of stranded commuters (after 3hours walking) and sojourn shelters (in circles) per 1kmsq

Figure 7. Dager analysis outputs

5. CONCLUSIONS

In this study, a simulation model which takes into consideration family safety information levels and shelter conditions on the behaviour of earthquake stranded commuters was proposed. Uncertainties in the decision-making process of commuters, as well as the interactions among commuters and its influence on personal decisions, are expressed by the model. Simulation experiments are performed by using data from Sapporo, Japan, where earthquakes are common weather phenomena.

Simulation outputs highlight the importance of family safety information on commuters' decision towards either facing an uncertain journey home or staying at safer locations, such as shelters. Even limited family information is shown to be effective towards reducing the number of walking-home commuters, thus reducing dangerous journeys. The study emphasises the fundamental role of information systems on disaster planning. Implementing information systems to provide family information, as well as providing information on road network and public transportation information (Cova and Johnson, 2002; Kagaya *et al*., 2011; Pel *et al*., 2011), would support stranded commuters' decisions.

Furthermore, availability of shelters and shelter environment conditions are highly important to commuters. Analysis of the arrangement of shelters within the study area based on the current scenario suggests that pre-establishing a shelter network throughout the city, while making such network known by the population, is an important measure towards reducing hazards posed to the population during earthquake and other natural disasters. *Enroute* shelters allow commuters to have sojourn breaks during their returning journeys, therefore contributing to safer trips. Favorable shelter environment conditions at companies and schools is also of significant importance towards motivating commuters to stay at their current location in place of facing dangerous walking journeys.

Road conditions, as previously discussed in the literature (Kagaya *et al*., 2005; Zhan and Chen, 2008), are identified as an influencing factor on route decision. In this research, road congestion level and liquefaction effect were input to the simulation model so as to reflect road conditions. These results are useful to evacuation management teams as an indication of the influence of post-disaster road conditions on route choice behaviour. However, further research is required in order produce empirical evidence of such influence. Results from the proposed path choice algorithm suggested that commuters choose their routes not only based on shortest paths, but also *enroute* changes are performed as a result of road conditions, as well as the numbers of commuters approaching intersections. Accordingly, the algorithm accounts for the interactions among commuters.

The modelling results presented in this study are based on a hypothetical earthquake experiment. Whilst results are not yet validated by empirical behavioural data, insightful indicators of travellers' behaviour are presented. These outputs may be used by disaster management teams in Japan and elsewhere as guidelines for further evacuation studies and shelter location planning.

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