Evacuation modeling considering field effects with Osaka Case Study

Jun Ji[1], J-D. SCHMÖCKER[2], J.S.E. TEO[3], H. YAMAZAKI[4], J. Y-T. LI[5]

[1] Student Member of JSCE, Dept.of Urban Management, Graduate School of Engineering, Kyoto University
C1-2-438 Kyotodaigaku Katsura, Nishikyoku, Kyoto 615-8540, Japan
E-mail: jijun@trans.kuciv.kyoto-u.ac.jp

[2] Member of JSCE, Dept.of Urban Management, Graduate School of Engineering, Kyoto University
C1-2-436 Kyotodaigaku Katsura, Nishikyoku, Kyoto 615-8540, Japan
E-mail: schmoecker@trans.kuciv.kyoto-u.ac.jp

[3] Member of JSCE, Dept. of Urban Management, Graduate School of Engineering, Kyoto University
C1-2-338 Kyotodaigaku Katsura, Nishikyoku, Kyoto 615-8540, Japan
E-mail: joel.teo@kiban.kuciv.kyoto-u.ac.jp

[4] Member of JSCE, Dept. of Urban Management, Graduate School of Engineering, Kyoto University
C1-2-436 Kyotodaigaku Katsura, Nishikyoku, Kyoto 615-8540, Japan
E-mail: yamazaki@trans.kuciv.kyoto-u.ac.jp

[5] Student Member of JSCE, Dept. of Urban Management, Graduate School of Engineering, Kyoto University
C1-2-438 Kyotodaigaku Katsura, Nishikyoku, Kyoto 615-8540, Japan
E-mail: joe.liyt@trans.kuciv.kyoto-u.ac.jp

Abstract: This research aims to study road network resilience under the influence of arc flow variation in the event of evacuation after an earthquake. A multi-agent model with mesoscopic traffic flow description is developed. The populations' choice functions that determine their evacuation decisions include the consideration of social capital in the form of an individual agent's compliance behaviour to government advice as well as field effects. The focus of this paper is a preliminary case study on the coastal area of Minato Ward, Osaka. The results show that a network trade-off is observed between the scenario of population heeding the government advice and the scenario of evacuees acting on their own without any information of shelters and network conditions. The paper discusses how such effects might be calibrated with data from previous disasters

Key Words: network, evacuation, social capital, evacuation, multi-agent, disaster, tsunami

1. Social Capital Concepts in Evacuation Model

Social capital has been defined in the past to refer to "the resources available to individuals through their social networks" (Lin, 2008) and encompasses trust and norm of reciprocity. The overall goal for resilient social capital in post-disaster recovery is to demonstrate that 'even highly damaged communities with low income and little aid benefit from denser social networks and tighter bonds with relatives, neighbours and extralocal acquaintances' (Aldrich, 2012). The advantages of a resilient social capital include more lives saved through community evacuation, self-organized civilian firefighting corps, community-driven relief distribution etc. (Aldrich, 2011). Such social capital characteristics are included in our novel agent-based simulation model.

The general view of evacuation model research can be summarised as shown in **Figure 1**. Evacuation plans in the form of route guidance or advice have been developed in the past by considering static and dynamic travel time and capacities with the use of traffic simulation. Performance measures such as casualties, travel times and network clearance time are evaluated. If the results are not acceptable, the evacuation plan goes through an optimisation model with improved strategies and subject to re-evaluation of the performance measures until an optimal supply management strategy is found. Recent studies have also included behavioural factors like compliance behaviour, herding behaviour or field effects to consider the effects of individual path choices and evacuating decisions that may be contrary to the advice given by the government. Researchers included such behavioural studies to obtain a more “realistic” evacuation plan and route guidance (Hsu and Peeta, 2014). The novelty of our research is to follow another stream of study, which considers both the advice and behavioural factors in social capital to evaluate the supply resilience strategy like retrofitting bridges by developing a mesoscopic agent-based model for the purpose.

The population agent’s utility function in our model includes their tendency to follow government advice and the consideration of “field effects”, that is the tendency to observe the behaviour of others to decide when, to where, by which route and mode to evacuate. The tendency to follow government advice is also termed as compliance behaviour, which has been modelled in the past to simulate evacuees complying fully with traffic management measures at intersections or to reject the advice and consider another path contrary to the advised path when there are no measures (Fu *et al.*, 2014). The agents included in our agent-based evacuation model are considered with reference from related literatures and past experience from the Tohoku earthquake in 2011 (Mas *et al.*, 2012, Mas *et al.*, 2013, Murray-Tuite and Wolshen, 2013).

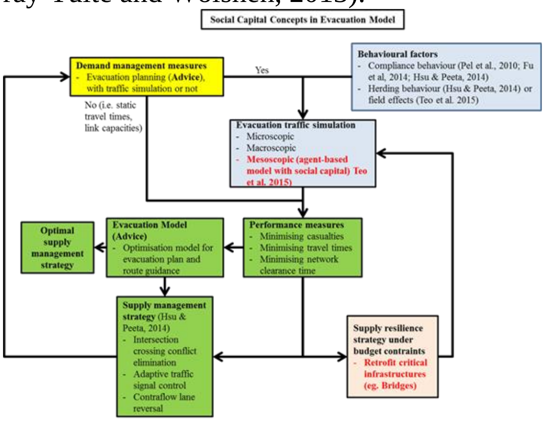

Figure 1. Flowchart of general evacuation model research

2. Modelling framework considering social capital

2.1. General framework

The general structure of our agent based model framework is shown in **Figure 2**. The active agents are the “top decision maker” and the population. The top decision maker will be connected to the government and is used here as synonym for the body responsible for controlling traffic in an emergency situation including giving advice to the population.

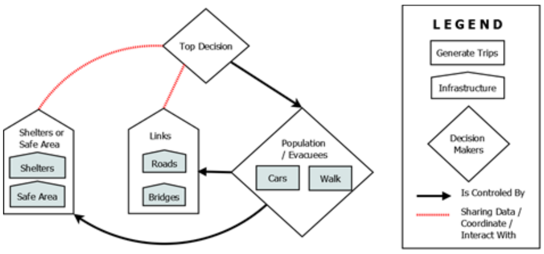

Figure 2. Simplified framework of stakeholders for evacuation simulation

Figure 2 shows that the population “is controlled by” the decision maker, though in our formulation of decisions we consider that the government advice is part of the utility function in the population’s decision to evacuate or not. For example the decision whether to evacuate or not at time t, $u_i^e(t)$, we formulate with following utility function:

$$u_i^e(t) = f\left(\eta_i, d^o_{h_i^p(t)}, \tau^z, m_i^e(t-1), e^a_{h(i)}\right) \quad (1)$$

The decision whether to evacuate or not is a function of η_i denoting whether the agent requires medical aid at the hospital or not, $d^o(t)$, the distance of the person to the risk area at time t, τ^z the evacuation target time, i.e. in case of Tsunami the expected time when the Tsunami arrives as well as two factors approximating our term social capital. Firstly, $m_i^e(t-1)$, describes the number of people who have started evacuating until time t-1. In line with our literature review, we suggest that this term positively influences the decision of others who have not yet started evacuating. Secondly, $e^a_{h(i)}$, describes the advice of the top decision maker whether to evacuate or not. The $\boldsymbol{\beta}$ parameters describe the relative weight of injury, distance to risk and urgency to evacuate in the utility function. Considering additive, linear effects of these five factors leads to following specification:

$$u_i^e(t) = \beta_i^i\eta_i + \beta_i^d d^o_{h_i^p(t)} + \beta_i^u\tau^z + \gamma_i^e m_i^e(t-1) + \zeta_i^e e^a_{h(i)} \quad (2)$$

where β_i^i, β_i^d and β_i^u describe the relative weight of injury, distance to risk and urgency to evacuate in the utility function. In general we would probably expect that β_i^i is set very high to ensure that those requiring medical help following the initial disaster (earthquake) are evacuating. Finally, γ_i^e and ζ_i^e are the weights of our “social capital” depending factors.

Similarly, we also formulate further decisions of those who have decided to evacuate such as destination choice, route choice and mode choice. For details on the agents’ route and path choice modelling as well as on the implementation into a newly developed agent-based model we refer to Teo *et al.* (2015).

2.2. Government advice

The government advice can be optimised given the location of the population, the available shelters as well as the targeted time until evacuation and the state of the network. Possible optimisation formulation for government responses are shown in Nagao *et al.* (2014) and Feng *et al.* (2015).

In this paper we assume though a simpler scenario. Through discussion with local governments as well as available literature from past disasters, it appears that a main criteria for advice must be simplicity. That is, for example, distinguishing advice by too detailed origins or making detailed plans for order in which population groups should evacuate might not be implementable in practice. Furthermore, reacting to dynamic events by changing advice during an evacuation is difficult so that dynamic evacuation plans might be too ambitious.

In the following we therefore simulate the impact of a very simple government advice scenario.

3. EXPERIMENT SETUP

Our multiagent model was tested on the network as shown in **Figure 3**. We focus on testing the effects that are of main interest in this paper, that is: (*i*) scenarios of arc flow variation and arc capacity variation and (*ii*) testing the effect of social capital in the form of following government advice and the field effect of following others under the two scenarios. **Figure 4** shows the locations of the bridges that are subjected to damage leading to a reduced link capacity, which illustrates the arc capacity variation that influences the network reliability. The scenario and case parameters are listed as follows (**Table 1**):

Study 1 – Arc flow variation comparison (cases with same residual capacity of 50%)

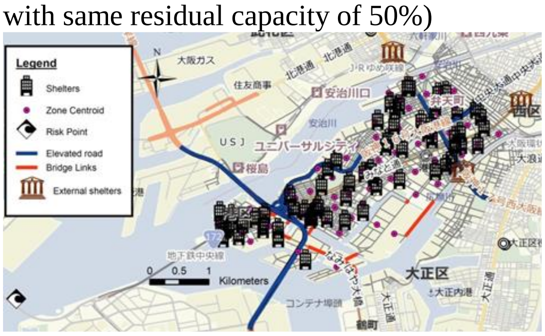

Figure10. Road network in Minato Ward

Table 1. Parameter settings for three cases with social capital factors

Case/Parameter	γ_i^{θ}	ζ_i^{θ}
Base case (Case 1)	0	0
Advice case (Case 2)	0	1
Field effect (Case 3)	1	0

With reference to equation (2), the value of $\gamma_i^{\theta} = 0$ means that the evacuees' utility function for evacuation does not consider the evacuation of neighbours at the previous time step and the value of 0 for ζ_i^{θ} meant that the evacuees do not consider the government's advice to evacuate.

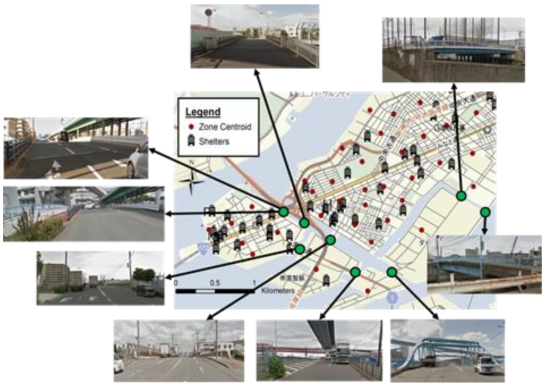

Figure 4. Bridge locations subjected to damage

The results in the following section will highlight just the effect of arc flow variation where the three cases, Base, Advice and Field effect are considered under 50% bridge residual capacity after an earthquake. In the Advised case, the evacuees located at the coastal area are told to move inland instead of occupying the tsunami buildings near the coast and those nearer the borders of Minato Ward are told to move to neighbouring wards due to the limited tsunami buildings to accommodate everyone. In the field effect case, at least half of the inland population of Minato Ward away from the risk point are assumed to have higher threshold against risk. The coastal area shelters are shown in **Figure 5**.

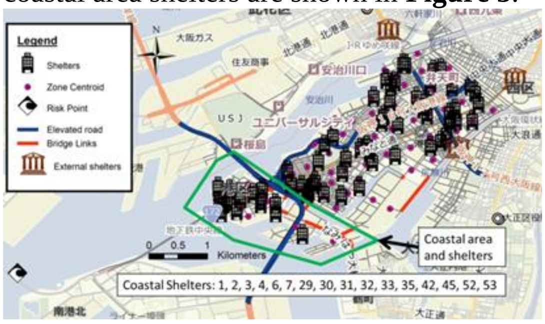

Figure 5. Area where coastal shelters are located

4. RESULTS AND DISCUSSION

It is shown in **Figure 6** that the number of evacuees in shelters or outside of Minato Ward is almost half of the population after 30 minutes compared to the base case. However, it should be emphasised that our current study deals with the initial 30 minutes after the earthquake and more analysis will be required for a longer study period of more than an hour in anticipation for a much higher wave from the Tsunami. The importance of a longer study period is higher especially when the capacity of the inland shelters of 42,301 has been reached in the base case.

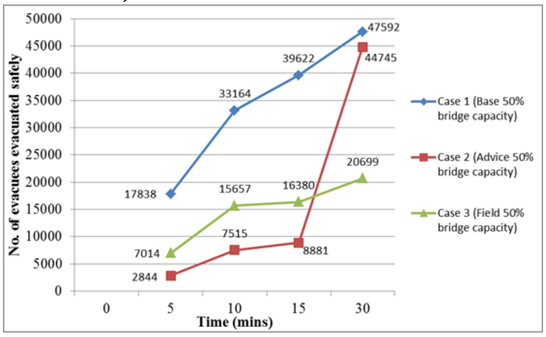

Figure 6. Number of persons evacuated after 30 minutes from earthquake event

5. PARAMETER CALIBRATION WITH TOHOKU DATA

An important issue for above case study as well as other evacuation models is that they usually only allow to illustrate “limiting cases”, e.g. assuming behavior as usual or system optimal evacuation. Since social capital factors might be important to consider especially for evacuation behavior though, parameter calibration becomes crucial. The tragic 2011 Tohoku earthquake generated data that can be used for these purposes. After the earthquake MLIT (Ministry of Land, Infrastructure, Transport and Tourism) and Csis (Center for spatial information science) conducted a survey to understand how, when and where people travelled after the earthquake. In the following we describe the survey data and how they might be used for data calibration.

5.1. Survey data

The survey was carried out in the form of questionnaire survey by MLIT in Aug 2011. 11492 samples from 5 prefectures in the hit region where collected. The following table lists a selection of the data that can be obtained from survey (Table 2).

Table 2. Selected data obtained from the survey

Type of information	**Notes**
Sociodemographic Information (person specific)	
Gender, Age, Occupation, prefecture and township of respondent	(basic personal information)
Household situation of respondent	describes whether there are children below age 7, older people aged over 70 and whether the household includes people with limited mobility
Person specific earthquake related information	
Location of person when the earthquake occurred	eg: workplace, home, car, bus etc
Home damage level	all or part of destroyed by tsunami or earthquake
Family impact	all safe, some injuries, death
Person specific tsunami evacuation related information	
Road worry	Whether the respondent worries about road condition when starting to evacuate

Reason for fearing the Tsunami and subsequent evacuation	1: flooding has been assumed according to the tsunami hazard map,2: large shake of the earthquake, 3: no tide embankment, 4: from experience, 5:persuaded by surroundings. 6:heard from local government
Reason for not fearing the Tsunami and hence not evacuating	1: flooding has not been assumed in the tsunami hazard map, 2: have an embankment, 3: away from the coastal areas4: from experience, 5: surroundings said Tsunami will not come, 6: no Tsunami information
Information source	1: TV, 2: Radio, 3: mobile, 4: public relations vehicles, 5: surroundings, 6: mail from cell phone, 7: internet
Shelter knowledge	whether the respondent knows the potential shelters well
Shelter condition	perception of shelter condition eg: too far, narrow, damaged etc
Information on trips after 2.46pm on March 11 by respondent	
Start and end time of trip, mode, route, purpose and "trigger"	(detailed information on travel behaviour)

5.1. Possible parameter estimation

Considering the decision whether to evacuate or not as well as evacuation timing, all of the factors listed in Table 2 might be considered as potential explanatory factors for trips made by respondents. In summary, the decision whether to evacuate or not is likely to depend on some socio-demographic factors as well as damages and injuries that might have occurred to a person during the earthquake and before the Tsunami. The survey further allows us to estimate variables specifically connected to social capital. Regarding the role of government advice, those who evacuate due to "government advice", can be distinguished from others using the information related to *Reason for fearing the Tsunami* as well as *information source*. Similarly, the role of others can be explained by this information as well as by considering the evacuation timing of others in the vicinity of the respondent.

The various modelling options as well as the transferability to our parameters γ_i^g and ζ_i^g will though require careful consideration.

6. CONCLUSION AND FUTURE WORK

This paper started by discussing the role of social capital in evacuation modelling. We then described some simple model formulation of factors related to social capital that have been implemented in an agent-based modelling framework. The model has been applied to Minato Ward, Osaka and we estimated the number of persons evacuated safely after 30 minutes from earthquake event. It is found that if the evacuees heed the advice from the government and in case where no information is available, the evacuation might be faster than if people rely on information obtained from their surrounding. We emphasise that these results are preliminary and that positive effects by relying on field effects might also be possible. Our initial results should mainly be taken as a proof of concept that social capital factors can in fact have a significant influence on the evacuation process. In the final section of this paper we emphasise the need to calibrate parameters related to evacuation and that the Tohoku data offer a good possibility to do so.

7. ACKNOWLEDGEMENTS

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