

A conceptual model of post-disaster travel behavioural responses: Case study of great east Japan earthquake 2011

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Abstract

In post-disaster communities where infrastructure and settlements are destroyed, after the initial recovery from survival mode people are forced to change their activity patterns, including travel behaviour. This research reviews the literature on this general type of situation and formulates a conceptual model of post-disaster travel behavioural responses that has both temporal and spatial components. Part of this model is tested empirically in one of the cities devastated by the tsunami following the Great East Japan earthquake in 2011. This paper distinguishes four phases – the pre-disaster situation; the emergency disaster phase; the temporary settlement phase; and the recovery phase – and construct conceptual and operational demand and supply models for each phase. Future hypothetical scenarios for the city are analyzed to illustrate the potential of the methodology. The research has policy implications for authorities charged with the responsibility of rebuilding communities. The short-term and long-term dynamics of behavioural responses of the residents assists planners of transport systems to provide services appropriate to the needs of the community, phased in over time, and opens the dialogue on what future type of settlement the people want, and whether re-building transport and land use can achieve more sustainable outcomes.

Key words: disaster management cycle; transportation planning model; scenario planning; smaller community, Japan

1. Introduction

Integrated response strategies to disasters are needed in order to create resilient communities capable of facing risks with growing flexibility (Sapountzaki et al., 2011). This entails linking actors and policies throughout the disaster management cycle, that has the following stages: (a) reconstruction and recovery, concerning the long-term activities aimed at returning an area to “normality” after severe devastation; (b) pre-disaster or preventive planning covering activities which range from the construction of defensive engineering works to land use planning and elaboration of evacuation plans; (c) preparedness reflecting alertness immediately before the onset of a hazard; and (d) response referring to reaction activities immediately before and after and (emergency) relief operations (Smith, 2001). The problem is that within this disaster management cycle spatial planning (and transportation planning) is largely absent. Spatial

planning “has the tools” to guide new residential, commercial, and economic development away from identified hazardous areas (Sapountzaki et al., 2011). Given that transportation planning is a component of spatial planning it is hypothesized that there must be a literature on decision support tools and techniques that can readily be applied to the recovery of communities devastated by natural disasters, such as earthquakes, floods, typhoons and tsunamis.

The aim of our research - more broadly into planning for resilient urban development (Campanella, 2006; Ganor, 2003; Godshalk, 2003; Haigh and Amaratunga, 2010) - is to develop decision support tools for governments responsible for the reconstruction of devastated, smaller communities. We have identified that much of the transportation research on post-disasters is US-based, where the planning authorities are generally well resourced to cope with strategic transportation planning tools and have professional expertise and data bases for decision support. For example, the US Federal Highway Administration/Federal Transit Administration (2007) offers a briefing book for transportation decision makers, officials, and staff. However, there are substantial resource constraints in the developing world, or in the smaller towns of the developed world, that has led us to search the literature for relevant tools and to propose a suitable methodology from first principles for post-disaster transportation planning.

The existing literature has rarely explored post-disaster transportation arrangements or mid-to long-term travel behavioral responses of residents remaining after a disaster (Section 2). Two years after the tsunami disaster in Japan, the challenges that transportation planners are facing are: how to re-design the transportation system considering the mid-term and long-term settlement and land use; and designs that enhance the preparedness for future events (Section 3). To address these challenges, the classification of the stages/phases of disaster based on lifecycle is useful as it helps to illustrate to what strategies could be considered or developed at the various stages of a disaster and how to move into the next stage (Ritchie, 2004). In Section 3 four phases are distinguished – the pre-disaster situation; the emergency disaster phase; the temporary settlement phase; and the recovery phase – and construct conceptual demand and supply models for each phase. The original research reported here focuses on planning frameworks and decision tools applied to a specific case study of Ishinomaki, Japan, that was impacted by the March 2011 earthquake and tsunami (Section 4). Scenarios of future spatial distributions of population and employment are constructed and the operational models are applied to estimate various performance indicators. The paper concludes with the implications to spatial planning in the case study city and research in the transportation field.

2. A review of research on decision support tools on post-disaster transport provision

2.1. Travel Demand

There is extensive research on the behavioral adjustments that urban travelers make in response to transportation disruptions, irrespective of whether caused by natural or man-made event. This literature includes travel behavioral responses to network disruptions caused by public transit strikes; bridge closures; special events, such as the Summer Olympic and the Winter Olympic Games; and earthquakes, floods and tsunamis. Most of these studies are largely descriptive of behavioral change – usually with descriptive statistics typically based on a change of traffic flows on highways and time of day of travel before and after the event. One of the most recent studies is by Zhu et al. (2010) who analyzed the adjustments to traveler’s decisions following the collapse of the I-35W bridge over the Mississippi River in Minneapolis in 2007 with a view to

better understand the short-term traffic dynamics and behavioral reactions to major transport network disruptions. This research follows a line of travel behavior research in North America prompted by natural disasters, or infrastructure repair and maintenance, such as the 1989 Loma Pieta earthquake in San Francisco (Ardekani, 1992), the 1994 Northridge earthquake, Los Angeles (Deakin, 1997; Guiliano and Golob, 1992), the traffic management operations during the I-195 Providence River Bridge Repair Project (Devine, 1992), and the 14-month closure for repair of the Centre Street Bridge in downtown Calgary, Canada (Hunt, 2002).

Zhu and Levinson (2008) identify short-term travel behavioral changes immediately after the network disruption:

- Change in the normal routes followed by drivers of vehicles because of road, and ramp closures or congestion caused by traffic re-allocating over non-affected routes;
- Adjustment in travel-time departure to avoid as much congestion as possible;
- Consolidation of trip purposes and, or, less frequent travel;
- Switch to alternative transport modes; and
- Share travel duties among family members

There has been less emphasis on modeling behavior with the notable exception of Osaragi (2012) and Holguin-Veras et al. (2003), who conducted a stated-preference experiment on New York residents six months after the September 11th terrorist attacks on the Twin Tower Buildings on lower Manhattan. They attempted to determine the process people use to decide whether to make an inter-city trip by airplane, train or automobile. Stated preference data were used to calibrate behavioral mode-choice models based on Random Utility Theory. Osaragi (2012) constructed several models that describe decision-making and behavior of individuals in a large city attempting to reach home on foot in the wake of a major earthquake. Probability models were calibrated using data taken from questionnaire surveys and person-trip surveys conducted in the Tokyo Metropolitan area. This simulation of the movement of individuals having decided to return home on foot was then applied to determine the spatio-temporal distribution of those who might be exposed to city fires that erupt during earthquakes.

Suarez et al. (2005) applied the traditional four-step transportation model calibrated for Boston, Massachusetts with a set of plausible assumptions to test the impacts of severe flooding scenarios. Assumptions include: a flooded road implies that the link is rendered useless, and therefore its capacity was set equal to zero; no trips were generated from flooded residential areas; commuting trips that have as destination a flooded industrial or commercial area were cancelled from the data base; and shopping trips that have as destination a flooded area were redirected to the closest commercial area. By comparing the transportation model run that incorporates these changes with the run under non-flooded conditions, a number of performance indicators were obtained. These include: the number of trips cancelled due to flooding of the origin or destination; the number of trips cancelled due to inability to go from origin to destination; the difference in vehicle miles traveled (VMT) and the difference in vehicle hours traveled (VHT), which is an economic impact based on the additional network delay that can be costed using the monetary value of time appropriate for the study area. Despite the efforts in understanding the transport demand and travel behavioral response after the unexpected disruption of transport network, the authors located no literature that analyzes the transition in transport demand and behavior, with the disaster management cycle. The recent work by Chang et al. (2012) examined the dynamics of urban disaster risk of 35 years in Metro Vancouver and link with casualties and transportation risk. However, the analysis was focused on the transportation disruption during the emergency phase, by the loss of a bridge.

2.2. Transport Supply

Studies of behavioral travel demand change is accompanied by quantification of damage to transportation supply. In most of the published studies of disruptions to the transportation system, diagrammatic maps show the links in the transportation network that have been taken out of service. However, a study by Chang and Nojima (2001) proposes transport performance measures for the situation before and after a disaster. One measure is the ratio of the network length open after the event to what was before the event took place (where 0 equates with total system failure; and 1 with a completely-functioning network). Another measure is the overall measure of the accessibility of the network based on network node connections before and after the event. It is worth pointing out that Kansky (1963), drawing on graph theory, came up with a wider array of quantitative indices describing transportation networks, including connectivity measures. Furthermore, if the spatial distribution of social and economic activities on the network (both before and after the event) is known then other measures of potential accessibility can be deployed (Guers, 2001).

2.3. Implications for Research in Smaller Communities

Whilst we agree with Sapountzaki et al. (2011) that spatial planning “has the tools” to guide new residential, commercial, and economic development away from identified hazardous areas this research have found no literature on post-disaster transportation planning for smaller communities like the ones encountered in Japan after the 2011 tsunami. Moreover, the focus of the literature is dominantly on tentative transport provision and travel behavioral response in the emergency phase. This guides the understanding of the emergency travel demand but fails to assist the spatial planning that requires to considering the resettlement and community preparedness. Recovery is a long-term process but the literature rarely focused on land-use and transportation planning support tool that assists the decisions in this context. Therefore, our aim is to develop transportation planning decision support tools for authorities responsible for the reconstruction of devastated, smaller communities. Institutional capacity is a pre-requisite irrespective of whether a special purpose reconstruction authority is established or not in the planning of resilient communities that encourage community participation from key stakeholders. From the literature review it is clear that there are quantitative tools for transportation supply analysis, travel demand forecasting and the kinds of behavioral adjustments that travelers make after natural or man-made disruptions to the transportation system. However, to the best of our knowledge no one has tried to put these tools together in one package that can form the basis of resilience in small communities, including in Japan.

3. Methodology

3.1. Conceptual model of travel and location behavior after disasters

One of the most explicit representation of travel behavior (both as a set of decisions made by individuals in response to the physical transportation system, and in response to the decisions of other travelers (especially in congested urban situations), is given by Teply (1982). In “saturated networks” travelers are forced to re-evaluate their decisions in response to excessive travel times

or "costs of travel" (Teply, 1982). Figure 1 shows a vertical sequence of decision processes that are categorized into one of six levels of travel choice.

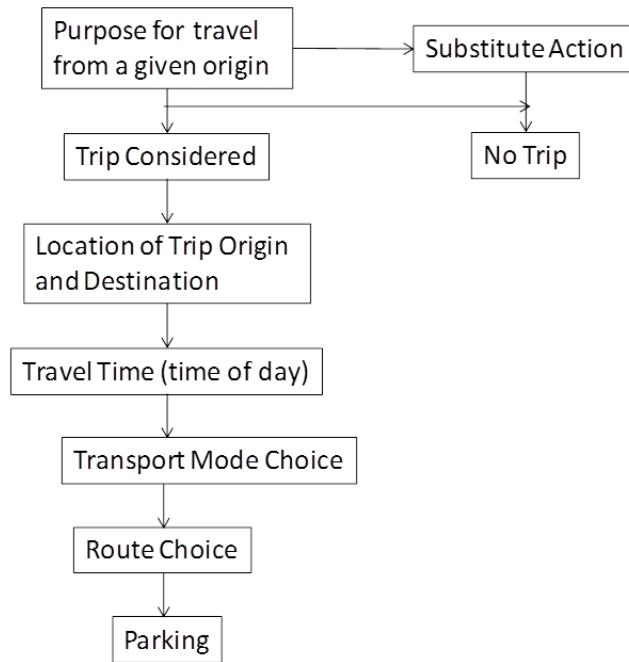


Figure 1 Decision process of travel choice

At the first level, choice involves considerations about the need and motivation for making a trip. If the activities themselves are not considered worthwhile then no trips are made. (The substitution of travel by tele-communications is relevant here.) The second level is about locational decisions that affect the origin and the destination of the trip. In the short term, this may involve choosing destinations closer to origins, or implementing trip chaining to reduce the amount of travel, but, in the long-term, level 2 includes relocation of residences and workplaces, and the rearrangement of social, cultural and recreational activities. The third level of choice involves time of travel (both the time of departure from the origin as well as the time of arrival at the destination, and this is clearly a complex phenomenon (Teply, 1982). In the advent of a disturbance to any established equilibrium (such as a transportation mode that is suddenly unavailable) the fourth level of choice indicates transportation-choice decisions: for user's of private transportation, a partial change (for example, use of park-and-ride) or a complete change to public transportation; for users of public transportation who are not captive riders there is a choice of private transportation. The fifth level of choice is where alternative routes that can be constantly modified on impulse at any point in time by motorists – there are various reasons for this change ranging from when an unusually long queue of vehicles is approached, or selecting another route just for a change of scenery. Finally, for the final choice (and one closely tied to route choice) is parking at the destination.

These levels of choice imply a stable home base and activity sets as represented by alternative destinations. Devastating events such as a tsunami destroy large parts of human settlements so there are inevitable re-locations of homes and activity destinations. This can be thought of as having four sequential phases. This research deconstructs the problem into four parts with each

corresponding to a major temporal event: an urban area and its travel patterns the moment before the disaster strikes; the situation with travel behavior and the transportation infrastructure and services during the disaster; the situation after the emergency survival mode period is over; and the long-term future as the urban area struggles to recover to normal - if indeed that is possible. We will discuss in each part the activity and travel behavioral responses involved, and identify potential data sources in smaller urban areas that could be used to operationalize the conceptual model proposed (Table 1).

Table 1 Temporal events in disaster time and potential data sources

Temporal Event	Potential data sources
Pre-disaster phase	Person trip surveys; traffic counts; strategic models of travel demand; Government secondary data on transportation infrastructure and public transport services Census
Emergency (disaster) phase	Media reports; damage reports by government authorities and NPOs; primary data through interviews and social surveys
Temporary settlement phase	Primary data through social surveys of travel and activities
Recovery phase	Government plans for reconstruction of communities; planning with land use and transportation model forecasts

3.1.1. Phase one - Pre-disaster

The pre-disaster time is defined as t minus h where h = one hour where t = the time that the disaster strikes. An estimate of travel patterns immediately before the disaster can be constructed if the study area has conducted person trip surveys that form the base year data to calibrate the four-step land use and transportation model (Black, 1981; Meyer and Miller 2001). Although such models are typically segmented into peak and off-peak periods, some comprehensive databases would allow a simulation of traffic over the road and public transport networks by time of day. Theoretically, it is a straight forward exercise to estimate urban travel patterns in the hour before the disaster event took place, but, as many researchers point out, data limitations preclude this. In the US substantial data has been assembled to allow synthetic parameters for the travel demand and supply models in smaller cities to be determined suitable for strategic transportation planning purposes (e.g. Waddell, 2002, 2007). The presentation of travel choice on pre-disaster phase is shown in Figure 1.

3.1.2. Phase two - Emergency (disaster) Mode

In partially destroyed transportation networks, residents are forced to re-evaluate both location and travel decisions, as illustrated in Figure 2. The factors that affect the decisions vary among individuals. By definition this event takes place at time, $t = 0$. Tsunamis are triggered by seismic

activities and the propagation of ocean waves is scientifically well understood. In the Pacific rim there is an international network of advance tsunami warnings (Monastersky, 2012) and there is always a gap between when the tsunami warning siren sounds on land and the moment the leading wave hits the shore. Depending very much on the land use, building codes and construction methods in any country the earthquake may or may not cause massive damage and loss of lives. Industrial and domestic fires are additional hazards to life as experienced at the time of great Hansin and Awaji earthquakes in Japan.

For those who survive the shock waves of the earthquake the critical split second decision is to get to higher ground or to the emergency buildings that are tall enough above the projected height of the water. In the aftermath of a tsunami there are those people who are drowned, those people who make their way to assist others (often children and the elderly) and are killed, those who are injured but survive, and those that move to safety. In the survival situation the options are limited. Options for the location to live is limited if the individual has to reside in temporary housing, and this affects transportation behavior. The immediate chaos of the aftermath puts everyone into survival mode - made more difficult with destroyed infrastructure, loss of power and water supply, petrol and food shortages, and the logistics of getting the injured and those elderly residents on home medical equipment, such as dialysis machines, to functioning health care facilities and hospitals. Bad weather (such as snow, in the case of East Japan in 2011) makes this survival period more problematic.

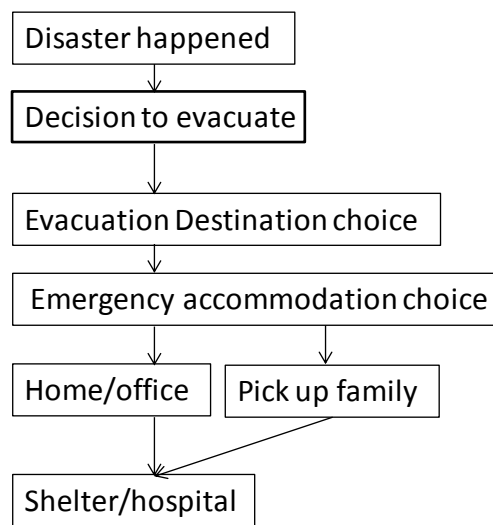


Figure 2 Decision process of travel choice in emergency phase

3.1.3. Phase three – Temporary Settlement

At time, $t = t + \text{delta}$, the housing, transportation infrastructure, new transportation services have gradually been restored so that it is possible to undertake primary data collection to determine travel re-adjustments and travel needs in a physical space of surviving activities that might be very different to that before the tsunami. Some people may return home to salvage what is left of their homes but soon most residents in the tsunami-impacted part of the settlements are required to move to emergency accommodation, or get to relatives or friends nearby to stay in non-impacted suburbs. Some people leave the area more or less permanently. The re-location of

people from emergency accommodation to temporary housing will depend on rates of construction. In the case of 2011 East Japan earthquake and tsunami, the construction of temporary housing started on the 22nd day after the event.

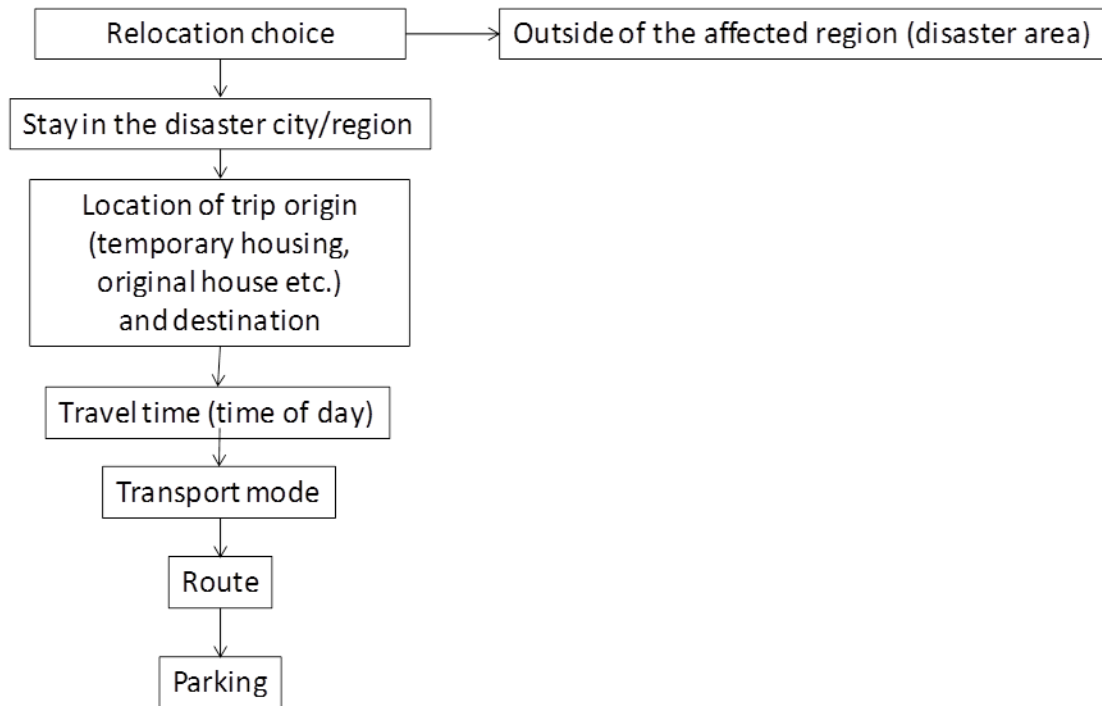


Figure 3 Decision process of travel choice in temporary resettlement phase

3.1.4. Phase Four – Recovery Phase

Central and local governments often make new institutional arrangements to assist with the rebuilding of communities. Depending on the complexity of planning reconstruction, and the involvement of stakeholders, including the community, this may take up to two years (Blakely, 2011). To generalize our conceptual model this research will assume that the strategic planning work and detailed urban design work is completed by time, $t + \epsilon$. Experience from previous natural disasters can shed some light on these recovery times (Kamel and Loukaitou-Sideris, 2004; Perry et al., 2003).

Authorities must make strategic choices as to whether to rebuild the human settlements in the same place, or relocate development to safer areas and abandon the former settlement. There is another important point: should the creation of a new settlement meet new urban design standards and aim to be more sustainable than the previous settlement? Once an urban layout has been determined, or preferably, as part of that planning process, land-use and transportation planning models can be applied to optimize designs given nominated objectives. Broad infrastructure costs and economic, social and environmental impacts and benefits can be estimated using standard procedures (US Federal Highway Administration/Federal Transit Administration, 2007). Future travel behavior in any case study area can readily be quantified if surveys have been conducted.

3.2. Japanese Study Area

The Pacific coast area of eastern Japan was struck by the Great East Japan Earthquake (Tohoku region) that occurred at 14:46 on 11 March 2011. The magnitude of this earthquake was 9.0 - the largest in Japan's recorded history (Suzuki and Kaneko, 2013). A number of tsunami waves hit North East Japan after the earthquake. The maximum height of the tsunami was 17.6m observed in Onagawa, Miyagi prefecture. An area of more than 507 km² was inundated. The total reported toll for Japan (as of February 21, 2012) was over 15,000 people killed and over 3,200 people missing (Government of Japan, 2012). 27,000 people were rescued. It was the scale of the human and physical damage (including to the Fukushima nuclear reactor) caused by the earthquake and tsunami that prompted Japan's Prime Minister to declare it "the toughest and most difficult crisis for Japan in the 65 years since the end of World War II". The earthquake and accompanying tsunami, struck a broad, rural area in the Prefectures of Fukushima, Miyagi and Iwate, responsible for generating around 4% of Japan's GDP. According to a Cabinet Office estimate, ¥16 trillion – ¥25 trillion (3–5 percent of Japan's GDP) in assets were destroyed, of which ¥9 trillion – ¥16 trillion were non-residential private-sector assets. The remaining ¥7 trillion – ¥9 trillion in losses were to social infrastructure including houses, ports, roads, and bridges (Nakamae, 2011).

Ishinomaki is located in the north Miyagi prefecture, on a lowland area at the mouth of the Kitakami River. The total population was 163,216 (October 2010). The gross population density is 288 persons per square kilometer. Employment by industry in 2010 was 6,246 persons (primary industry), 20,702 persons (secondary industry), and 42,909 (tertiary industry). In Ishinomaki, the maximum height of the tsunami was 8.6 m and these waves inundated about 30 % of the coastal plains (Figure 4). 2,960 people were killed and 706 people are still officially missing (as of September 2011) - about 2.2 % of the population can be assumed to have died. 70 % of houses (53,742) were affected, of which 40% (22,357) were completely destroyed. 50,000 people were evacuated from their homes to 250 shelters (City of Ishinomaki, 2011).

Ishinomaki city council issued the *Ishinomaki Recovery Master Plan* in December, 2011 (nine months after the disaster), followed by the *Implementation Plan* (February, 2012), and the *Maintenance and Improvement Plan* (April, 2012). The *Master Plan* includes the principles of recovery, and group re-location to safer areas. Ishinomaki city council has decided to review its *Transport Plan* that had been developed before the tsunami disaster. The group re-location of 61 communities has already been decided in Ishinomaki, whereby residents in vulnerable area are resettled in available land away from the coast. A new urban district is planned as 127 hectares, with the land development completion targeted for 2014.



Figure 4 Major transport infrastructure and tsunami line in Ishinomaki Region (Map created by authors. The tsunami inundation line data is sourced from the Reaction Project for the 2011 of the Pacific Coast of Tohoku earthquake by the Earth Environment Engineering Group, the University of Tokyo)

3.3 Data and Scenario Analysis

For the purpose of this paper, traffic demand in Ishinomaki was analyzed with regard to the four phases: pre-disaster phase; emergency phase; temporary settlement phase, and recovery phase. In this section, the data sources and the conditions for the analysis are explained.

3.3.1. Pre-disaster phase

For the pre-disaster phase, a normal weekday traffic situation before the disaster had to be approximated because no transportation study had been published by Ishinomaki city council. Normally, in Japanese cities, travel demand is estimated by the four-step method, with disaggregate mode-choice models and equilibrium road traffic assignments. These models are based on data from surveys such as person trip surveys. However, there are no data for Ishinomaki city, as it has never been included in any person trip survey area. Also, no

transportation supply surveys have been conducted. Thus, our traffic demand analysis is relied on the three-step method, where trip distribution between each traffic zone pair is estimated based on socioeconomic data of each zone (e.g. population and employment) while the four-step method estimates trip generation/attraction of each zone based on the socioeconomic data prior to the estimation of the trip distribution. Although the three-step method is simpler than those methods mentioned above, it will be adequate for the purpose of this analysis that is to approximate traffic demand in regard to the four phases. It also should be noted that the boundary line data of small areas per district per town in Ishinomaki were collected from the Geospatial Information Authority of Japan and the data were converted into traffic zones for this analysis (see Figure 5).

In order to calculate the trip distribution between respective zones, the following production-constrained gravity model was used:

$$T_{ij}^{(1)} = \frac{P_i^{(1)} \cdot A_j^{(1)} / t_{ij}^\gamma}{\sum_{j=1} A_j^{(1)} / t_{ij}^\gamma} \quad (1)$$

where $T_{ij}^{(1)}$ is daily trip from zone i to zone j for phase one (i.e. pre-disaster phase); $P_i^{(1)}$ is population (2010) of zone i ; $A_i^{(1)}$ is employment (2010) of zone i ; t_{ij} is travel time from zone i to zone j ; γ is the parameter relating to travel time resistance. The population of each zone in 2010 was collected from the National Census Japan 2010 while the employment of each zone in 2010 was proportionately estimated from the Economic Census Japan 2006. Travel time between each zone was estimated by firstly calculating the shortest distance between each zone based on the road network data, explained later, and then dividing the distance uniformly by 30 km/h as travel speed. The parameter γ was assumed to be 0.3 (which is representative of friction factors in small communities). The model has the following restriction in Equation 2:

$$\sum_{j=1} T_{ij}^{(1)} = P_i^{(1)}. \quad (2)$$

Regarding modal share, public transportation ridership is low and was assumed to be 5% of person trips since the public transportation ridership of local city areas and the regional hub city areas (Ishinomaki is classified into these types of area in Japan) are about 2.5% and 4.5%, respectively, according to the Person Trip Survey Japan 2010. Therefore, the numbers of trips between zones by car were calculated based on the following: 95% of travelers travel by car for zones where there is at least one bus-stop or one station; 100% of travelers travel by car for zones where there is not any bus-stop or station.

For traffic assignment, the traffic network was constructed by consolidating the road line data from the Digital Map 25,000 published by the Geospatial Information Authority of Japan. While there are various methods of traffic assignment, such as the incremental assignment, the user equilibrium assignment, stochastic assignments, etc., the all or nothing assignment - where traffic demands of zone pairs are assigned only to shortest paths between the zone pairs - was used for this analysis as road capacity constraints are not a major issue. The method will be adequate for the purpose of this analysis where it did not need an exact result but a rough sketch as we will be

contrasting the post-tsunami situation based on the same methodology. In all scenarios that follow it is obvious that no attempt has been made to include commercial vehicle traffic in the analyses.

3.3.2. Emergency phase

Just after the tsunami hit Ishinomaki city, many parts of the city were flooded, and almost every activity was suddenly forced to stop as almost every road was flooded. In this analysis, therefore, it was assumed in the traffic situation in the emergency phase that trips from or to the flooded zones are zero and the others are same as pre-disaster phase. That is, trip distribution was re-calculated as follows:

$$T_{ij}^{(2)} = \begin{cases} 0 & \text{if zone } i \text{ and/or zone } j \text{ is flooded zone} \\ T_{ij}^{(1)} & \text{otherwise} \end{cases}, \quad (3)$$

where $T_{ij}^{(2)}$ is trip from zone i to zone j for phase two (i.e. emergency phase). Also, the road network was reconstituted in the supply model by eliminating roads in the flooded areas. The flooded areas were set based on the tsunami inundation line data sourced from the Reaction Project for the 2011 of the Pacific Coast of Tohoku earthquake by the Earth Environment Engineering Group, the University of Tokyo. The other parts of the three-step method follow those in the pre-disaster phase.

3.3.3. Temporary settlement phase

For the temporary settlement phase, a hypothetical scenario in Ishinomaki on July 2012 was assumed: the construction and the moving-in of temporary houses, which had been planned by the city government, had already been completed at that time; and this was complemented by a field land-use survey conducted by the authors in August 2012. As a result of field observations, we estimated that roughly 40% ~ 50% of houses and business offices had remained, or been reconstructed, on the once flooded residential and business areas. Accordingly, the population and the employment of each zone for phase three (i.e. temporary settlement phase) were modified as follows:

$$P_i^{(3)} = \begin{cases} 0.5 \times P_i^{(1)} + H_i & \text{if zone } i \text{ is flooded zone} \\ P_i^{(1)} + H_i & \text{otherwise} \end{cases}, \quad (4)$$

$$A_i^{(3)} = \begin{cases} 0.5 \times A_i^{(1)} & \text{if zone } i \text{ is flooded zone} \\ A_i^{(1)} & \text{otherwise} \end{cases}, \quad (5)$$

where $P_i^{(3)}$ is population of zone i for phase three; $A_i^{(3)}$ is employment of zone i for period three; H_i is the number of people living in temporary house in zone i in July 2012. The data about the temporary houses, such as the location or the number of people living, were sourced from the Miyagi Prefectural Government. The other parts of the three-step method follow those in the pre-disaster phase.

3.3.4. Recovery phase

In Ishinomaki the recovery phase has not been completed at the time of writing, so a future scenario must be constructed to represent a possible recovery phase. Recovery could be a time to restore the original city activity, or a turning point to develop a more sustainable city by achieving transit-oriented development or a compact city. Given the present uncertainty about future plans for the local government area of Ishinomaki, four different scenarios were formulated by the authors as possible futures of the recovery phase.

Scenario-A is assumed to be the original situation before the disaster - that is, exactly the same as the traffic demand in pre-disaster phase. Scenario-B is a transit-oriented development scenario that is similar to the original situation except that public transportation ridership rises from 5% in the original situation to 15%. This figure is chosen because the public transportation ridership in a regional central city (such as Sapporo, Sendai, Hiroshima and Fukuoka/Kita Kyusyu) is roughly 15%, according to the Person Trip Survey Japan 2010. Scenario-C was assumed to be a situation where residents who had lived in the flooded areas would be relocated to town areas that have higher density than pre-disaster time. This group relocation would not only aim to get rid of threats of future tsunami disasters but would also aim to construct a more compact city – although this is not included in the local government’s plan at this stage. Figure 5 shows the zones from where and to where the group relocation is assumed to take place, where the zones to where the group relocation are selected is according to the relocation plan sourced from Ishinomaki city council. Also, the population of the zones from where the group relocation takes place is assumed to be zero. The total number of relocated people is distributed in proportion to the area of the zones to where the group relocations are planned. Employment of each zone is the same as before the relocation (i.e. pre-disaster phase one). Specifically, the future population of each zone is calculated as follows:

$$P_i^{(c)} = \begin{cases} 0 & \text{if zone } i \text{ is a zone from where relocation is} \\ P_i^{(1)} + \frac{S_i}{\sum_{rt} S_j} \times \sum_{rf} P_k^{(1)} & \text{if zone } i \text{ is a zone to where relocation is} \\ P_i^{(1)} & \text{otherwise} \end{cases}, \quad (6)$$

where $P_i^{(c)}$ is population of zone i for Scenario-C; S_i is area of zone i [square-km]; $\sum_{rf} P_k^{(1)}$ is summation of $P_k^{(1)}$ only for zones from where relocation is; $\sum_{rt} S_j$ is summation of S_j only for zones to where relocation happens. The total amount of relocated people calculated is 20,269. The other parts of the three-step method follow those in the pre-disaster phase. Scenario-D is a combination of Scenario-B and Scenario-C - that is, a transit-oriented developed compact city situation. Therefore, urban form conditions for Scenario-D are almost the same as Scenario-C except that public transportation ridership rises from 5% to 15%.

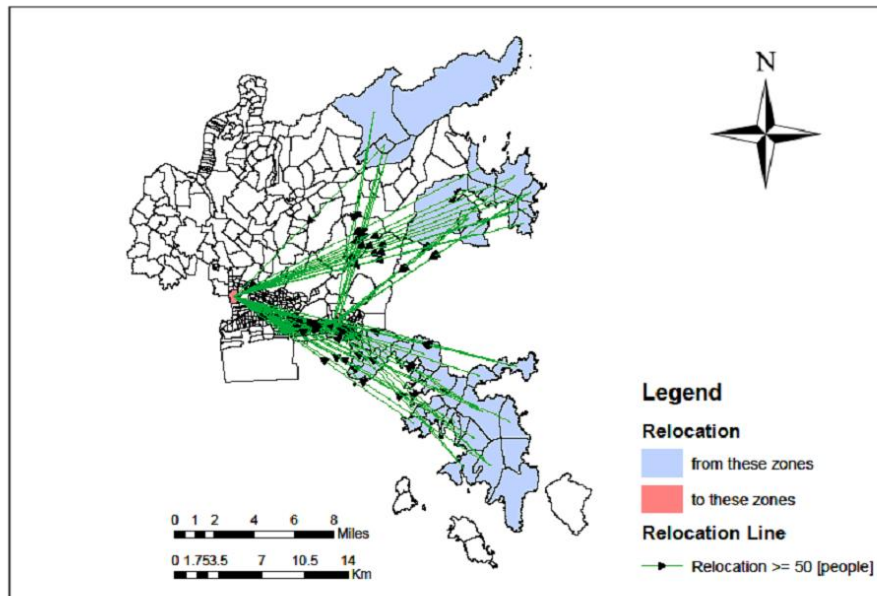


Figure 5 Zones from and to where the group relocation is, and the amount of relocated people (map created by authors, relocation plan is sourced from Ishinomaki city council)

4. Conclusion

This research has proposed a methodology to analyze transportation demand in a post-disaster small community, where the temporary settlement and group re-location of residents has been considered. From the literature review, no studies have developed a decision support tool to analyze the transportation demand and travel behavior in the phases of temporary settlement and recovery of the disaster management cycle. After conceptualizing the temporal events of transportation travel choice before and after the disaster time, this research have applied the model to one of the devastated communities in Japan following the March 2011 earthquake and tsunami - Ishinomaki in Miyagi prefecture. The detailed results of the analysis and implications to planning and research will be presented at the conference.

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