Behavioural analysis and modelling of family gathering during the 2011 Tohoku tsunami evacuation

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Preface

This report is the result of my graduation project at the faculty of Civil Engineering and Geosciences at the Delft University of Technology for the degree Master of Science (Transport & Planning). All the work in this report was made possible by all the knowledge and experience acquired over the course of my two year study period at the university.

First and foremost, I would like to thank my daily supervisor, Adam Pel, for his support and advise throughout my thesis research. His comments and patience have been very helpful to keep myself on the right track and complete my project. I would also like to thank other committee members for their help and guidance. I owe great gratitude especially to Jeroen van der Gun for his close guidance and effort to develop and run the model.

Apart from my thesis committee, I want to thank my fellow students also working on their thesis projects for their encouragement and sympathy for this challenging work. It would have been impossible to enjoy my graduation work without them.

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Summary

Due to the the climate change which makes natural hazards more intense causing more severe impacts on the society and the economy [12], more institutions are expected to take actions to minimize the impact. Among those natural hazards, earthquake and tsunamis are the most devastating in terms of the number of casualty [63]. Evacuation is one of the most effective way for people to deal with tsunami, and the institutions can develop evacuation planning to facilitate the evacuation. Evacuation modelling can be carried out to enhance evacuation planning, investigating consequences by different scenarios and disaster management strategy.

Conventional evacuation modelling tends to assume that family members are to be together in the face of tsunamis and evacuate as a household or each person evacuate individually otherwise. This assumption however can cause an inaccurate prediction when taking family gathering behaviour into account [45, 50], which was reported to have occurred during the 2011 earthquake off the Pacific coast of Tohoku in Japan [14, 56]. This is an intermediate trip made prior to or during evacuation to pick up children at school or return home to evacuate with other family members, thus it is a mixed trip of a household trip and an individual trips (Figure 1.1). In order to cope with those trips, Activity Based Model (ABM) needs to be applied where trips made by a traveller during a certain period of time are chained taking multiple activities performed by the traveller into account.

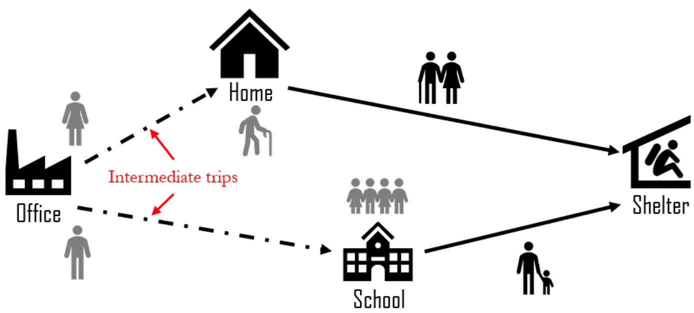


Figure 1: Intermediate trips for evacuation

The objective of this research is two-folds; one is to gain insights into evacuation behaviour considering family gathering activities, and the other is to present a methodology of how those behaviours can be modelled in a simulation. As for the former objective, a behavioral analysis was carried out using the survey data of evacuation by the survivors of the 2011 Tohoku tsunami [37] in order to identify statistically significant travel choices and parameters defining travellers who performed the family gathering during the evacuation. With respect to the latter, a methodology was sought to model the particular evacuation behaviour identified for the former objective and the model was simulated using the general activity-based transportation model developed by van der Gun et al. [66].

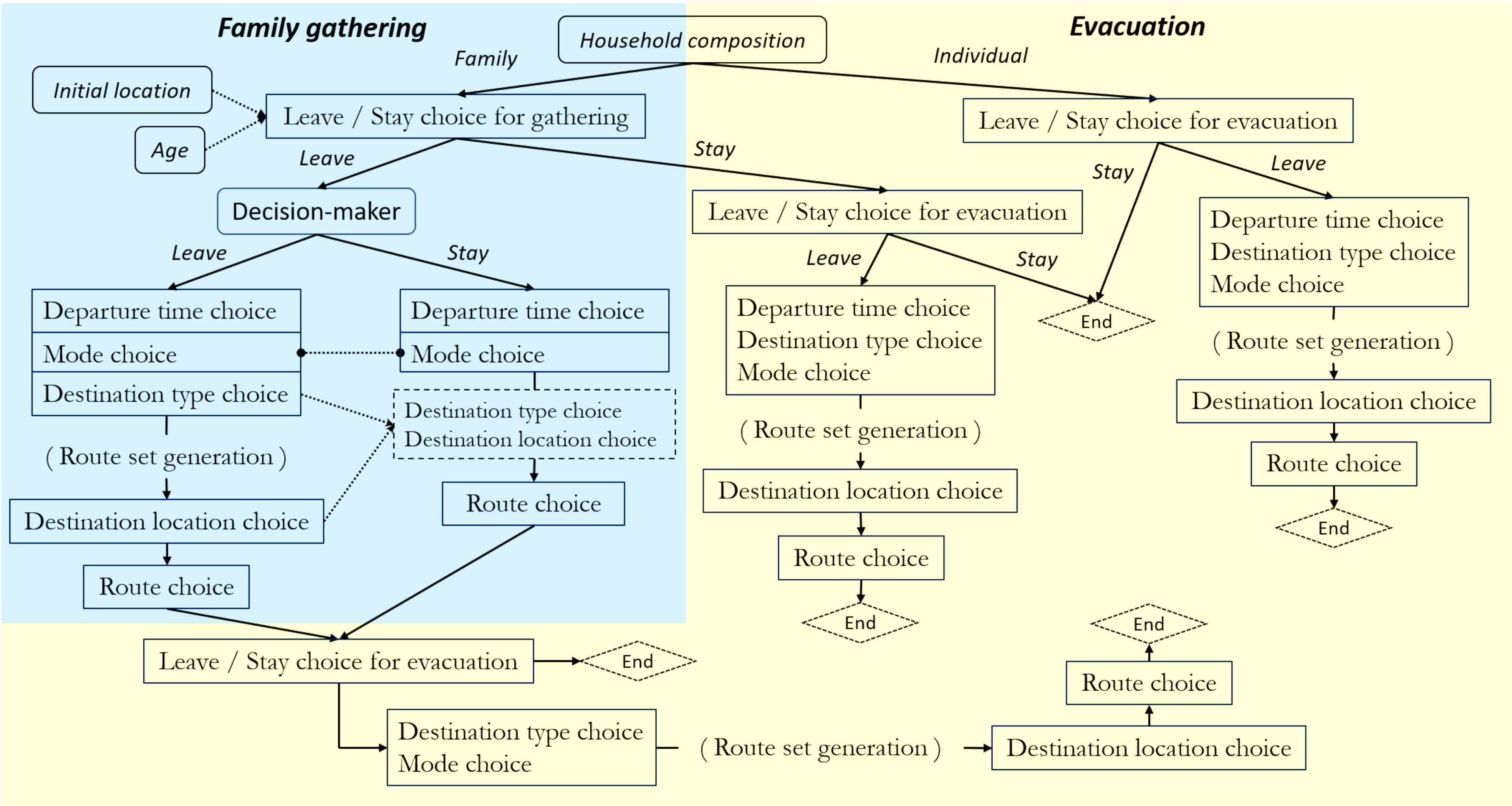
As for the travel choices, all the three hypotheses formulated mostly based on expert's judgement have been rejected, indicating some travel choices made by those who performed

the family gathering are statistically different from those who did not perform it. Concerning the parameters defining those who performed the family gathering, out of the four hypotheses designed based on previous studies, three attributes, initial location, gender, and age have been found significant. Those findings are;

- People who performed the family gathering were less likely to evacuate than those who did not.
- Departure time distribution for the evacuation trips and the family gathering trips are significantly different.
- People who performed the family gathering were more likely to evacuate by car than those who just evacuated.
- People initially at "Work" were more likely to perform the family gathering than people initially at "Home".
- People initially at "Shops" or "Outside" were more likely to perform the family gathering than people initially at "Work".
- Women at 20-59 having children were more likely to travel to "School" compared to "Home" for the family gathering than men in the same condition.
- Younger people having elder person in their households were more likely to perform the family gathering than elder people having elder person in their households.

The choice frequencies of alternatives developed in the behavioral analysis have been applied into the model formulation taking these findings into account (Figure 4.8). Depending on whether they performed the family gathering, different choice frequencies have been applied for the mode choice while different distributions for the departure time have been applied after estimating the parameters of the model based on the survey. Additional interaction between the household members for the mode choice has been incorporated such that the household members in the same area share a car. Besides, initial location and age have been taken into account for the leave / stay choice. Two important assumptions have been made for the choice frequency of the survey to be applied to model the joint decision-making among household members. One is that the respondents for the survey are representatives of households, and the other is that there is a decision-maker in each household whose decisions are followed by the other household members. In order to check the applicability of the model, a simulation has been carried out. The result shows severe congestion in some areas resulting in the evacuation completion rate after three hours being 63.8%. It was found that the characteristics of the family gathering trips in comparison with the evacuation trips are explained by the faster speed achieved by the earlier departure time and by the longer travel distance caused by the destination choice being fixed locations such as home and relative's home rather than nearby buildings. The validity of the model has been discussed by comparing the simulation result with the survey, showing some improvements needed in terms of modelling car passengers and choices geographically unconditioned, which can be further studied in the future.

Scientific contribution has been made in terms of evacuation behaviour and evacuation modelling methodology for the family gathering during evacuation. Also, taking this particular behaviour into account for evacuation modelling leads to better prediction of evacuation trips, which in turn helps develop enhanced evacuation planning.



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1

INTRODUCTION

1.1. Background

The impact of natural hazards on human and economical losses has become more serious over the past decades partly because of the climate change, and scientific research for example indicate that the climate change would increase the number of extreme weather events and make those events more intense [12]. According to a think tank of the World Bank, IED, the reported number of natural hazards increased significantly between 1975 and 2005, and the reason for this can of course not be attributed solely to the climate change but also to the improved reporting and recording conditions [21]. Nevertheless, the fact remains that more institutions such as governments and agencies are aware of it and are expected to take actions to minimize the impact.

In order to cope with the increasing number of natural hazards, an enhancement of resiliency is considered an essential approach for any physical and human systems threatened by those hazards. Critical infrastructure systems such as utility lifeline systems and transportation system are especially high-priority targets for the resilience enhancement since it plays important roles in the face of natural hazards [58]. Freckleton et al. [16] introduce a resiliency cycle consisting of normalcy, breakdown, annealing, and recovery which can be applied into a resiliency of transportation system. Starting from a normalcy condition, an event-driven breakdown causes a degradation of the system performance due to damaged infrastructures or event-induced demand. Annealing is a process of the progression of the transportation system toward the normalcy and a new equilibrium can be sought based on the degraded condition during this process. Recovery is required if the transportation system is physically damaged so that it can regain or exceed the level of service present before the breakdown.

Evacuation is a travelling phenomenon particularly prompted by natural hazards, and those induced demands affect the resiliency of transportation system since it largely defines the system performance during the phases of breakdown and annealing. Evacuation have been considered worldwide as a protective action against natural hazards and can be defined by the size and notice given by a hazard [71]. These temporal and spatial conditions in turns depends on the type of hazards and the population geography of affected areas. Among the various type of hazards, earthquakes and tsunamis are the most devastating disasters with respect to the number of deaths caused by the natural hazards recorded between 1998 and 2017 [63]. The reason for this could be partly explained by the characteristic of tsunamis that could affect a vast geographic spread of coastlines. The Indian Ocean tsunami in 2004 caused catastrophic damages in a global scale, ranging from Indonesia in the Southeast Asia to Somalia in East Africa, and is considered the world's first truly global disaster [2]. The 2011 earthquake off the Pacific coast of Tohoku in Japan (the 2011 Tohoku tsunami) produced tsunamis extending about 500 km along the coast and killed 15,782 people [23].

1.2. Problem Statement

Transportation modelling for evacuation is a powerful tool for evacuation planning to investigate how different scenarios or disaster management strategies affect transportation systems and people using it under emergency conditions. Pel et al. [50] and Murray-Tuite and Wolshon [45] provide reviews on the research and development of evacuation traffic simulation models rather focusing on the evacuation by cars (e.g.Lindell et al. [26], Fu et al. [17], Chen and Zhan [8], and Zhang et al. [75]). Not statistically verified, but overall it appears that a plenty of studies emerging from the U.S. in 90's and 00's which focus on hurricane evacuation have contributed more to the evacuation research although evacuation by other natural hazards such as floods and earthquake have also been studied in countries at risk of those hazards. The reason why more evacuation modelling research are conducted per hazard type is, as mentioned earlier, that different hazards have different characteristics and different impacts on transportation system and human behaviour. According to Lim et al. [24], evacuation can be separated into small or large scale and immediate (no-notice) or pre-warned (short-notice). The pre-warned evacuation is further categorized into mandatory, recommended, and voluntary. In case of tsunami evacuation, even if warning system functions properly or preceding earthquakes can be considered as a notice, since the time given for evacuation is so short compared to e.g. hurricanes, it is considered as no-notice event. The time allowed for evacuation varies significantly depending on location, depth, and magnitude of earthquakes. For instance, whereas the major tsunamis caused by the 2011 Tohoku reached the nearby coasts about after 30 to 60 minutes after the earthquakes [41], the same took about 10 hours to reach the California coast [70].

Despite the separated research per hazard type, there is no difference among the hazard types, and even from rather normal transportation modelling, in that it models a series of choices travellers make, namely stay/leave choice, departure time choice, destination choice, mode choice, and route choice. The stay/leave choice defines the total number of evacuees whose outcome is used in all the subsequent models, and this choice could be made simultaneously with the departure time choice. The factors affecting the stay/leave choice are, for example, socio-demographic characteristics and disaster characteristics. The destination choice determines the type of locations to evacuate such as shelters, hotels and family/friend's house, while the mode choice defines by what mode, for example, car, public transport or walking, the evacuees travel to the locations. The final choice, given those preceding choices, is the route choice in which the evacuees decide the route they take from the departure location to the destination by the mode in a transportation network.

One of the issues in the evacuation modelling addressed by Pel et al. [50] and Murray-Tuite and Wolshon [45] is intermediate trips. These are trips made prior to or during evacuation to pick up children at school or return home to evacuate with other family members, first addressed by Murray-Tuite and Mahmassani [43, 44] (see Figure 1.1). Several surveys conducted after the 2011 Tohoku tsunami reveal that there were not few people who waited for family members to drive home [14, 56] whereas a experimental study of post-earthquake intentions in New Zealand shows that about a half of the people has an intention to reunite with family members to evacuate together [67]. The conventional transportation modelling, however, can not be applied to capture those trips because it is a trip-based approach in which trips are linked only by two points and chained trips by an individual are treated as separated trips [49]. As a result, most evacuation modelling tends to assume that family members are to be together, often at home due to data availability to estimate people's location prior to evacuation, before the evacuation begins, and evacuate as a household or each person evacuate individually. Applying the trip-based approach into the evacuation modelling, therefore, can cause an underestimation for the former case or an overestimation for the latter case in the prediction of evacuation trips in terms of evacuation time and traffic.

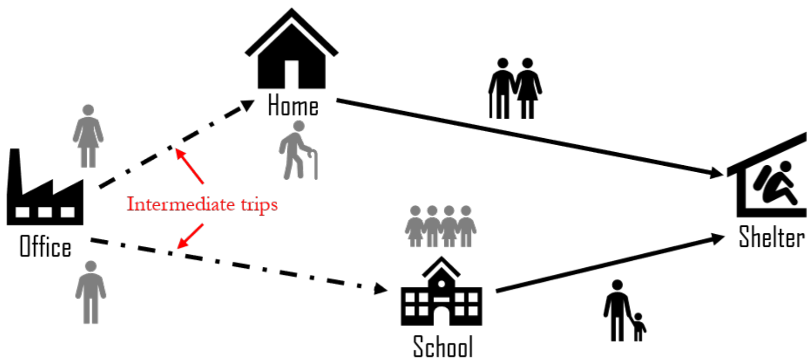

Figure 1.1: Intermediate trips for evacuation

Those inaccurate predictions of evacuation demand results in less effective evacuation planning, which is often developed based on the demand predicted by those models. It is not difficult to imagine, for example, evacuation routes or evacuation shelters planed based on the underestimated demand can have insufficient capacities, leading to congestion in certain locations. An example of problems caused by the overestimated demand can be given in evacuation planning on demand side. Shimamoto et al. [53] argue, assuming two hours of evacuation time before the arrival of tsunami which is likely to occur according to the Central Disaster Prevention Council in Japan, that managing vehicle evacuation timing, so-called “evacuation staging”, can reduce the total evacuation time. In this case, the overestimation of demand can cause unnecessary delays in later evacuation stages, putting someone's life in danger.

1.3. Research Opportunities

Survey data

Ministry of Land, Infrastructure, Transport and Tourism of Japan (MLIT) conducted a large-scale survey of evacuation among the survivors of the 2011 Tohoku tsunami at the aim of developing the evacuation management such as evacuation routes, shelters and guidance [37]. The survey was conducted from September to December 2011 at the 62 cities in 6 prefectures affected by the event, collecting 10,603 valid samples by face-to-face interviews to individuals. The respondents were asked about their action, perception, and situation after the occurrence of the earthquakes, and their prior preparedness for tsunami. Besides, the respondent's personal information such as gender, age, and the presence of mobility-dependents in their family were collected. The data provides in-depth information regarding their evacuation behaviour such as when, where and how they evacuated for what purpose, offering a great opportunity to investigate into the intermediate trips.

Simulation model

A transportation simulation can be made roughly by two components; choice modelling (demand) and traffic flow modelling (supply). The choice models predict the number of trips per OD, mode, and route, and the traffic flow models calculate based on the demand route travel cost, i.e. travel time, given a transport network since the travel time can be varied depending on the demand and the network capacity. But this calculation process needs to be iterative in case of an equilibrium to be assumed because the demand is also dependent on the travel cost, which can be sometimes challenging in terms of computational efficiency. This problem is relaxed in the model developed by van der Gun et al. [66] who propose a general activity-based transportation model for simulating multi-modal transportation networks during emergencies. The authors developed a network loading model with mesoscopic or macroscopic traffic representation which can be well integrated into the microscopic choice models, and also the iteration process is made efficient by introducing a parallel procedure not needing an equilibrium assignment because of assumed on-trip route choice. The choice models are developed to offer a great flexibility with regards to the specification of the choice behaviour by applying an activity-based escalation model incorporating three possible behavioural states of individuals. In “evacuation state”, the intermediate trips can be incorporated in the choice models by joint decision-making among household members.

1.4. Research Objective and Question

Given the statements given in the previous sections, the objective of this research is set to be as follows;

> *Gaining insights into evacuation behaviour considering family gathering activities, and presenting a methodology of how those behaviours can be modelled in the simulation.*

In order to meet the first part of the objective, firstly, the survey data needs to be analyzed to identify behavioural characteristics for those who performed the family gathering in comparison with those who didn’t. In addition, an investigation should be made as to what are parameters attached to those who performed the family gathering. Therefore, two research questions are formulated for this part as follows;

> *RQ1. What were the evacuation choices by people who performed the family gathering significantly different to those who did not during the 2011 Tohoku tsunami evacuation?*
>
> *RQ2. What were statistically significant parameters defining those people who performed the family gathering during the evacuation?*

For the latter part of the objective, a methodology is sought to model the particular evacuation behaviour identified in the 1 and 2 research questions and the model is simulated using the general activity-based transportation model. Hence, a research question for this part is set as follows;

RQ3. How those family gathering behaviour can be modelled in the activity-based transportation model for emergencies?

There has not been a research to date in which family gathering behaviour derived from actual tsunami evacuation is incorporated in a transportation simulation. Hence, a contribution of this research project to evacuation modelling research is twofolds; first, family gathering behaviour during the tsunami evacuation is presented empirically, and second, it provides a methodological explanation of how the behaviour can be modelled in a transportation simulation. Lastly, since these insights are derived from a specific event, a final research question below is needed to meet the objective.

RQ4. How those insights about the evacuation behaviour can be generalized for the future tsunami in different places?

All the research questions will be answered step by step leading to the objective of this study as explained in the next section.

1.5. Methodology

The research is conducted in the following steps. Using the survey data, statistical hypothesis testing is performed to find significant travel patterns related to the family gathering. The result of this analysis is formulated as to the travel choices made by those who performed the family gathering as well as the attributes by which they are characterized such that it can be incorporated into the model developed by van der Gun et al. After that, a case study is performed for a Japanese coastal community conducting a simulation in order to present the applicability of the model. All the steps are accompanied by literature review. A literature review on empirical research for evacuation behaviour would help understand the characteristics and make the statistical analyses more scientific. The methodology for evacuation modelling needs to be understood by a literature review on rather general evacuation modelling so that the model adaptation can be performed in a appropriate manner. Besides, the advantage and the characteristics of Activity Based Model, which this research will apply, over the conventional modelling approach can be studied by a literature review on advanced transportation modelling. The steps are illustrated in Figure 1.2.

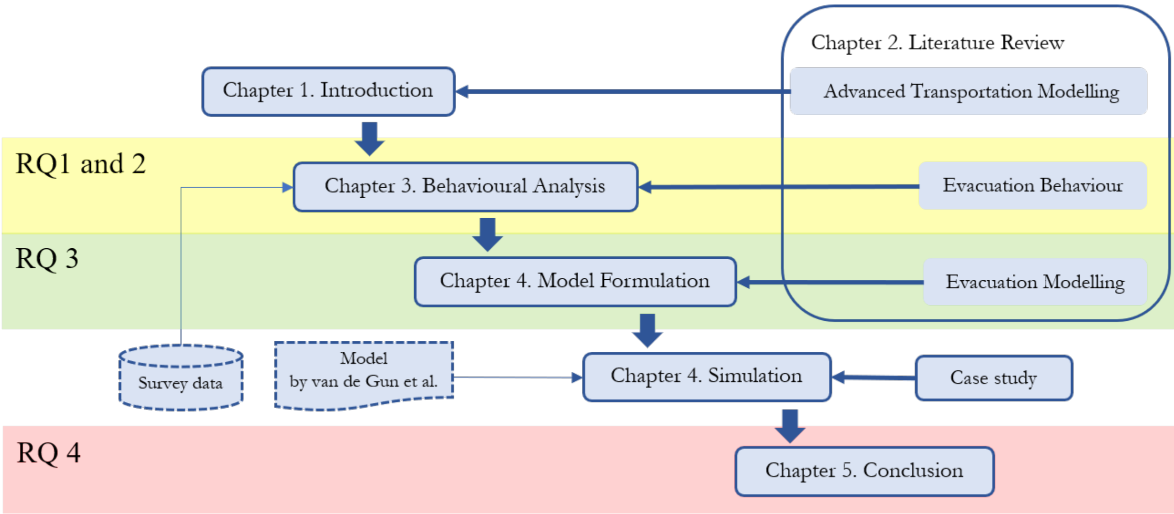

Figure 1.2: Research methodology

The rest of this paper is organized as follows. In Chapter 2, the literature review is provided in which evacuation modelling is discussed from behavioural perspective and methodological perspective. Behavioural analysis is presented in Chapter 3 consisting of data analysis, hypotheses formulation, and statistical tests. In this chapter, RQ1 and RQ2 will be answered. In Chapter 4, the model formulation is discussed referring conclusions from the previous chapter, leading to answering RQ3. In the same chapter, a simulation is presented in which a case study from a coastal community in Japan is performed. Lastly, conclusions and discussions are given in Chapter 5, answering RQ4, to finalize the research project.

2

LITERATURE REVIEW

Evacuation studies have been addressed most frequently from two disciplines; transportation engineering and social sciences [59]. The former attempts to develop modelling techniques that solve specific planning problems such as estimating travel times of evacuees and understanding how evacuation planning improve the performance while the latter deals with behavioural assumptions behind transportation models trying to explain how people act in emergency situations. In this chapter, literature review is presented in three sections; "Advanced Transportation Modelling", "Evacuation Modelling", and sayEvacuation Behaviour. In the first section, "Advanced Transportation Modelling", a general description of advanced transportation modelling are provided presenting some advantages of the approach for transportation and evacuation modelling in which the two disciplines can be well integrated. In " Evacuation Modelling", the first discipline is introduced presenting evacuation modelling research accompanied by simulation in which several evacuation choices are considered, leading to a completed evacuation model. After that, the second discipline is discussed in " Evacuation Behaviour" providing some empirical studies that attempt to explain evacuation behaviour. A conclusion for this chapter is summarized in the final section.

2.1. Advanced Transportation Modelling

In this section, first a general modelling approach that has been applied in various disciplines, Agent Based Modelling and Simulation, is explained leading to the transportation domain. Then, a transportation-focused modelling approach, Activity Based Model, is presented discussing its advantages over the conventional modelling approach in order to argue the necessity of advanced modelling approaches for evacuation modelling considering the family gathering activity.

Agent Based Modelling and Simulation

Agent Based modelling and simulation (ABMS) is an advanced modelling approach enabling to simulate the behaviour of dynamic complex systems and has been applied widely in many different fields in the past decade thanks to the recent advances such as higher computational capacities and data richness. ABMS consist of agents that interact within an environment and the agents have certain essential characteristics. According to Macal and North [32];

- Agents are self-contained and may be heterogeneous. An agent is an individual with certain attributes which can either differ or not differ from other agents. Thus, each agent is distinguishable and recognizable to each other.
- Agents are autonomous and may be goal-directed. Each agent behaves independently in its environment and in its interaction with other agents based on rules, goals or models set on the agents.
- An agent is defined by a state consisting of a set or subset of its attributes. Having various states for an agent enables the set of behaviours to be richer.
- An agent is social and may be adaptive, having dynamic interactions with other agents and adapting their behaviours based on its accumulated experiences.

Agents can be various entities such as individuals, households, and even organizations, and being able to capture emergent phenomena resulting from the interactions of those entities is a great benefit of ABMS according to Bonabeau [4], who introduce “Flows” of people as one of the four areas of applications for situations of interests where emergent phenomena may arise. In a built environment such as building or roads, flows of people emerge and each of those people can have different behaviour or different destinations to go but they are forced to interact with each other especially in physically or institutionally constrained environment. Therefore, ABMS attempts to model each individual by having a synthetic population consisting of entities. However, the unit of measurement of the conventional approach is not an individual, but rather the number of trips emanating from any particular zone. The conventional approach predicts probabilities of alternatives to be chosen using aggregate data in zones and thus it does not deal with individual choices. Because of this, people are considered rather homogeneous within fractions and the behavioural aspects of individuals, which are listed above, are often dismissed. Modelling each individual enables to incorporate heterogeneity into decision makings of the individuals or households by including explanatory variables in choice models such as income and age, which makes up for the lack of behavioural realism of the conventional approach. Besides, the conventional approach does require each modelling step to be connected only on an aggregate level, i.e. the fraction of population choosing certain alternatives, thus there is no need to have a consistency on individual traveller level between each modelling step. An example for this can be found in a separated modelling procedure between the destination choice and the route choice. For the route choice modelling in the conventional approach, the number of travellers choosing a certain route from one zone to the other is computed based on the trip demand between those two zones by an assignment method, e.g. all-or-nothing and deterministic user-equilibrium, leading to the number of travellers on each link. As this computation is performed for each OD pair, the total demand on one link is the sum of those outcomes. As a result, travellers on those links can no longer be linked to the demand on the OD pairs defined by the previous modelling step, the destination choice modelling.

Activity Based Model

Activity Based Model (ABM) is a specific form of ABMS developed for transportation modelling and can be contrasted with a trip-based modelling approach as shown in Figure 2.1. The trip-based approach attempts to model the individual person trip often in the peak hours where trips from home to work (or vice versa), home-based work (HBW), are dominant but

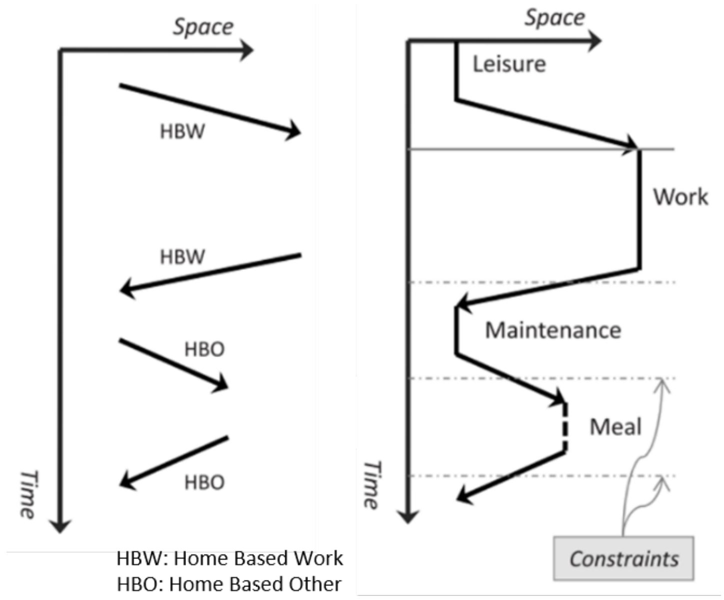

Figure 2.1: Trip-based approach (left) and Activity-based approach (right) [49]

other trips made by the same traveller, even the return trips from work to home, are modelled separately. In activity-based approach, on the other hand, trips made by a traveller during a certain period of time are chained taking multiple activities performed by the traveller into account, which is often achievable by modelling individual travellers. A fundamental premise of this approach is that travel demand derives from people's needs and desires to participate in activities [5]. In order to model those activities realistically, several constraints can be introduced, which is an important aspect of ABM. According to Arentze and Timmermans [1], the following constraints can be identified;

- A person, transport mode and other schedule resources cannot be at different locations at the same time. (situational constraints)
- Opening and closing hours of institutions such as offices and shops influence the earliest and latest possible times to implement a particular activity. (institutional constraints)
- Households commitments such as bringing children to school dictate when particular activities need to be performed and others cannot be performed. (household constraints)
- Particular activities cannot be performed at particular locations, and also individuals have incomplete information about the opportunities that particular locations may offer. (spatial constraints)
- Activities do require some minimum duration and both the total amount of time and the amount of time for discretionary activities is limited. (time constraints)
- An individual cannot be at a particular location at the right time to conduct a particular activity due to the specific interaction between an individual's activity program, the individual's cognitive space, the institutional context and the transportation environment. (spatial-temporal constraints)

These constraints can be easily associated with the evacuation modelling involving family gathering activities. In order for a family member to pick up a child at school by car in the face of an earthquake with a risk of tsunami, for example, to begin with the child needs to be at school and that is likely defined by school hours (institutional constraints). However, only that does not guarantee the child present at school since it is also possible that the school conducts a group evacuation which is not necessarily communicated to parents (spatial constraints). Besides, anyone having no car at the time is unlikely to be able to perform the activity under the emergency condition (situational constraints) while, due to the risk of tsunami, one needs to consider time allowed to perform the activity (time constraints). Needless to say, the activity itself can be a household constraint where one of the family member needs to commit.

Three different modelling approaches have been distinguished by Rasouli and Timmermans [52] who evaluate progress made in the development and application of ABM: (i) constraints-based models, (ii) utility-maximizing models and (iii) computational process models. Constraints-based models do not predict individual and household activity–travel patterns unlike the other approaches, but check the feasibility of generated activity agendas under a specific space-time constrains defined in terms of locations, their attributes, available transport modes and travel times between locations by different transport modes. Utility-maximizing models, known as discrete choice models, assume that people choose activity-travel pattern alternatives that maximize their utilities (RUM: Random Utility Maximization). Extending trip-based models, it often applies nested logit models in which, for example, conditional probabilities of an individual performing primary tours and secondary tours are jointly estimated. Computational process models, also called rule-based models, attempt to mimic the underlying decision-making process, relaxing behaviourally unrealistic assumption of utility-maximizing behaviour. It postulates that individual/household's preferences defined by their goals drive the choice of activity participation, jointly with prior commitments and constraints. In case of household activity patterns, activities are scheduled interactively with other household members ensuring the activities can be performed under e.g. spatial–temporal and institutional constraints. Albatross is known for the most comprehensive model in this approach.

2.2. Evacuation Modelling

In this section, various evacuation modellings are presented dividing it into three section; Hurricane evacuation, Tsunami evacuation, and Evacuation with family gatherings. First, a couple of examples are provided from hurricane evacuation modelling since it is a type of natural hazards leading evacuation research as explained earlier. And then, more spaces are given to present studies for evacuation of the concerned hazard, tsunami, which provides different choice sets in modelling compared to the hurricanes such as destination choice and mode choice. Finally, literature on evacuation with family gatherings is provided in more detail. The hazard types researched for this are mostly no-notice events like tsunami since, as explained earlier, families are assumed to be united prior to evacuation for short-notice events like hurricane not needing to model the family gathering activities.

Hurricane evacuation

From an early stage of the development of ABMS for evacuation modelling, several research using rather simplified ABMS have been found dealing with hurricane evacuations. Chen et al. [9] applied VISSIM V3.70, a behaviour-based microsimulation system developed by PTV, to investigate evacuation efficiencies under hypothetical hurricanes. While the choices, trip generation, trip destination, and route choice, are defined by simple deterministic approaches, the advantage of ABMS is introduced in modelling driving behaviours defined by the speed difference between vehicles and by the psychological characteristics of individual driver-vehicle units. Chen and Zhan [8] conducted simulations using Paramics, a microscopic simulation system, in order to research evacuation efficiencies comparing two kinds of evacuation strategies given the three types of road network structures. Same as Chen et al. [9], car following and lane changing behaviour are modelled in detail depending on the position, velocity, and rate of acceleration/deceleration of each vehicle whereas default rules in Paramics were applied for trip generation, destination choice and route choice not being discussed. Zhang et al. [74] used an agent-based toolkit, Repast Simphony, to investigate evacuation efficiencies but they applied an agent-based simulation technique into the route choice in addition to the driving behaviour. The routes to evacuate are chosen by either the shortest distance to the destination or the least congestion depending on the types of agents, normal agents and greedy agents.

Tsunami evacuation

Mas et al. [35] developed an agent-based simulation model for the 2011 Tohoku tsunami evacuation using Netlogo and performed a case study for a coastal community in the Sendai plain area, validating the model by the model output of casualty with the actual casualty in the area. The evacuation participation rate is defined subjectively as 84%. The departure time is, on the other hand, randomly chosen from a distribution bounded by the result of stated preference survey by Suzuki and Imamura [57] and the recorded arrival time of the tsunami on March 11th. The research by Suzuki and Imamura [57] was also referred for the mode choice taking only cars (72%) and pedestrians (28%) into account and two evacuation destinations are assigned, both of which are in turn used for the traffic assignment where the A* (A star) algorithm on grid spaces is applied and a speed reduction due to the congestion is considered. Mas et al. [36] applied a similar model into a case study in La Punta, Peru, having multiple traveller types defined by the maximum possible speed depending on age. The departure time is defined in the same way as Mas et al. [35] after validating it by stated preference surveys. Three different scenarios defined by destination choice, only horizontal/only vertical/a combination of the two, are tested in order to investigate the shelter capacity against the simulated demand. A similar attempt is also made by Trumikaborworn et al. [62] for a case study of Khao Lak, Thailand.

Another agent-based simulation model for the 2011 Tohoku tsunami evacuation by cars and pedestrians has been developed by Makinoshima et al. [33] using various source of information including the survey by MLIT. Assuming the evacuation participation rate to be about 90%, the evacuation departure time is defined by a cumulative function of the evacuation departure time obtained by the survey by MLIT. While the destination choice and the route choice for the pedestrians are simplified by the nearest and shortest rule, those by cars are defined by the relative difference of distance to each destination against the nearest evacuation building and the estimated actual distance to each destination for the destination choice, and the fastest route but more weights are given to main roads for the route choice. In addition to the congestion effect on the speed of cars and pedestrians learned from Mas et al. [36], the interaction between cars and pedestrians are also taken into account for the speed of car. The simulation model was validated referring different source of information. Nagao et al. [46] developed an agent-based simulation model for car evacuation considering the congestion observed during the evacuation in the 2011 Tohoku tsunami. Despite the fact that the authors used different survey data to model each evacuation choice and validated the model with the observed traffic collected from probe data, as the emphasis is given to evaluate the evacuation planning, the model parameters are not provided in the paper except the route choice where the shortest path algorithm is applied. The route choice considers the travel distance, the travel time and the number of turning points.

Fujioka et al. [18] presented an agent-based simulation model for pedestrian evacuation with the objective of evaluating evacuation management system. The agents are defined by different attributes such as decision-making capability and susceptibility to information in addition to walking speed, which affect the route choice. The evacuation choice and the departure time choice are set to be the same, evacuating right after the tsunami alarm, for all the evacuees while the agents are given two types of destinations, places far-away from the coast and evacuation shelters, chosen first by the distance. In order to investigate evacuation management system, another agents who may reject the evacuees evacuating to the shelters and give them information are created. Although the model is tested in a case study showing the evacuation management system can be effective to save their lives, as the focus is placed on the simulation methodology, the parameters used in the model is not based on empirical data but the author's judgement.

Wang et al. [68] applied Netlogo to develop an agent-based simulation model for tsunami evacuation scenarios and performed a case study in the city of Seaside, Oregon. Instead of constructing a deterministic model, emphasis was put on model sensitivity analysis where different model parameters are adjusted in order to investigate how these affect the mortality rate. The choice to evacuate and the mode choice are explicitly combined by defining four options; no evacuation, horizontal evacuation on foot, horizontal evacuation by car and vertical evacuation, which are assigned by a simple probabilistic approach. The departure time, on the other hand, is separated into two, immediate evacuation and delayed evacuation, and the latter is modelled using a Rayleigh distribution whose parameters, a delay time and a scale parameter, are investigated in the sensitivity analysis. The destination choice and the route choice are simplified by choosing a nearest location and a fastest route out of eight evacuation areas located outside of the tsunami inundation zone and three vertical evacuation structures within the inundation zone assuming different speed of walking and driving. In order to take congestion effects into account, cars speeds are to change depending on how much densely an agent is surrounded by cars. This probabilistic model for evacuations, however, does not pay much attentions into behavioural aspects which differ among the evacuees and all the agents are modelled in the same way. One reason for this could be assumed to be a lack of empirical analysis. Extensively applying the model, Mostafizi et al. [39] conducted a network vulnerability assessment to identify the most critical set of links and created a retrofitting resource allocation framework based on the assessment. For the sake of the supply-side oriented study, most model components followed or simplified the original model except the vehicular movement in which a car-following model is applied using calibrated parameters. Furthermore, Mostafizi et al. [40] customized the model in order to analyze the impact of the location of the vertical evacuation shelter on evacuation mortality rate. Whereas the choice for the vertical evacuation shelter is defined deterministically, the location selection problem from the planning perspective is examined considering three factors; minimum milling time, average walking speed, and the percentage of people who consider vertical evacuation.

2004 Indian Ocean earthquake and tsunami triggered tsunami evacuation research to be performed for Southeast Asian cities. Goto et al. [19] presented an agent-based model applied for a simulation in Banda Aceh, Indonesia. Considering the possible mixed traffic of vehicles, motorbikes, and pedestrians, which is more common phenomena in the country, they incorporated the complex congestion effects into the speed of the agents. Multiple scenarios are set for the departure time choice and the mode choice based on the survey conducted locally, while the destination choice is defined by the shortest distance based on 9 evacuation destinations depending on the modes. Di Mauro et al. [10] developed an agent-based model for Penang, Indonesia, by referring a number of literature and the consultation work. Two extreme scenarios, vehicles(20%)/motorbikes(80%) and pedestrians(100%), are tested with an optimistic estimation that people evacuate directly after the earthquake and go straight towards the high ground or the closer vertical evacuation shelter. The contribution is rather given to modelling vehicular/pedestrian movement in which a meso-scale approach is applied in order to deal with assumed unusual traffic composition. For this reason, the traffic at the road junctions is modelled with a micro-scale approach while the traffic along the road is modelled with a macro-scale approach, using sound traffic variables in literature such as road capacities and free-flow speed.

Evacuation with family gatherings

Using the established ABM, The Comprehensive Econometric Micro-simulator for Daily Activity-travel Patterns (CEMDAP) [3], Lin et al. [25] developed a tool to study how evacuation-specific activities or the timing of emergency alert affect the transportation system performance. The evacuation-specific activities were defined to incorporate responses of the emergency by each individual interacted with other family members within a household. To this end, a set of intuitive rules was applied for the households with/without children that pick-up activities need to be performed depending on the vehicle availability and the presence of children. The result showed that the interaction of individuals within a household affects the transportation system performance depending on the timing of the emergency alert. For example, in case of an alert in the middle of day like at noon there are higher chances that family members are more dispersed in an area and the pick-up activities in that situation increase, resulting in the overall longer travel time due to the congestion. It should also be noted that a dynamic traffic assignment, VISTA, was applied in order to predict the travel times in time on network links at a fine resolution.

Murray-Tuite and Mahmassani [43, 44] presented optimization-based simulation models that incorporate household trip-chaining behaviour in an emergency situation. Assuming no-notice evacuations during the daytime in which dispersed household members gather and then evacuate by car as a single unit, the authors applied linear integer programs to determine the meeting location for the household members and which driver should pick up which non-driving household member given a rather simple small network. Those resulting household decisions for the different type of households are used as inputs for the traffic simulation program and the sequence of pickups and the travel time are presented. The authors applied this framework further to study overall effects by the activity chains on the network clearance time by expanding the number and type of households to be simulated based on the census. Later on, Liu et al. [28] developed further the idea of linear integer programs taking more diversified evacuation behaviours into consideration. Instead of only the household members picking up their children at school, they proposed to include facilities such as schools and day care centres relocating the children and the elder people to other sites with better accessibility so that pick-up activities by their family members are performed more efficiently. Besides, the authors added buses as a mean of the evacuation where a logit model was applied, using only the initial travel time as a variable, to determine the probability that a certain mode will be chosen. Furthermore, in order to achieve true optimal set of relocation sites, iterations between the optimization model and the simulation model were introduced as the relocation sites first determined by the simulation model affects road traffic which in turn affect the simulation model (Figure 2.2). Scenario analysis for mode shifts and sensitivity analysis for the arrival time of car/bus were performed presenting various optimal relocation sites.

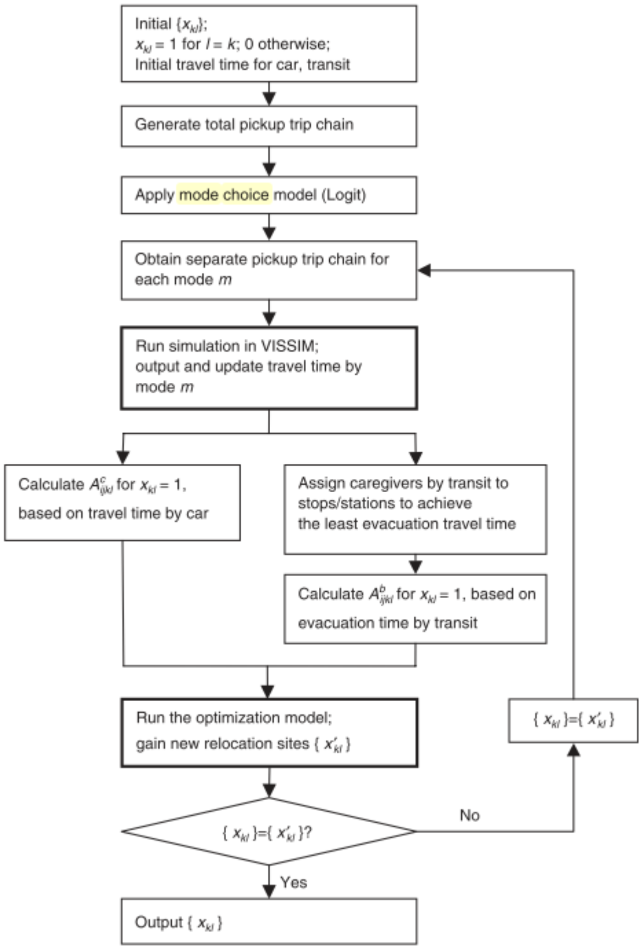

Figure 2.2: Flowchat of optimization-based evacuation model for family gathering [28]

Liu et al. [30] developed a framework of the four-step transportation model incorporating family-gathering activities and examined the effects on evacuation efficiency and network performance. As shown in Figure 2.3, the family-gathering activities are incorporated into the first part of the four step models, trip generation, usually consisting of population synthesis and loading departure time. Because work/school locations and vehicle allocations need to be defined first to model the family-gathering activities, unlike an activity-based model for planning purposes (such as TRANSIMS) where these are defined in the following steps (trip distribution & mode choice), simplified methods are applied for this research. And then, the family-gathering choice is modelled by the estimated logit models [29], after which, in case of multiple family-gathering activities, the sequence of the activity chains is modelled. Since the survey data did not provide significant information with respect to this activity chain, it has been assumed that the activities are performed first for the one closer to the individuals who perform the activities. It also should be noted that the logit model applied for the family-gathering choice assumes the independence of irrelevant alternatives (IIA) property, but this does not hold in case of multiple children to be picked as the alternatives of the children may share unobserved factors. To deal with this problem, one arbitrarily selected child was used for the model specification and the resulting model was validated using another child. For loading departure time, a sigmoid curve [51] is applied. After defining the destination choice and the mode choice, a dynamic traffic assignment is applied having interactions with the destination choice. The presented model framework was tested in the Chicago metropolitan area, assuming no-notice events to occur during school hours, with two cases with/without the family-gathering activities considered. The planning software VISUM with a dynamic user equilibrium (DUE) was applied but it uses OD matrices rather than chained trips as inputs for traffic assignment, thus a compromised solution was suggested that the chained trips are broken into multiple trips, estimating departure times of subsequent trips based on zonal travel time from VISUM and modifying OD matrices for certain time periods. The result shows that the case with the family-gathering activities for a major incident will significantly reduce proportions of evacuees who reach safe zones by a certain time and average travel speed compared to that without the family-gathering activities. This model, however, has been developed out of a stated preference survey assuming hypothetical no-notice evacuations. Despite the fact that stated behaviour data also has some degree of predictive validity [22, 69], there is a contradicting argument by Sun et al. [55] presenting that actual evacuation behavior is different from evacuation plan. The authors also suggest that more surveys and interviews being conducted when it comes to a transferability of the family-gathering behaviour models in different contexts. Furthermore, the network used for the simulation is assumed not to be affected by the event, which is not the case when it comes to tsunami possibly causing certain disruptions on evacuation routes.

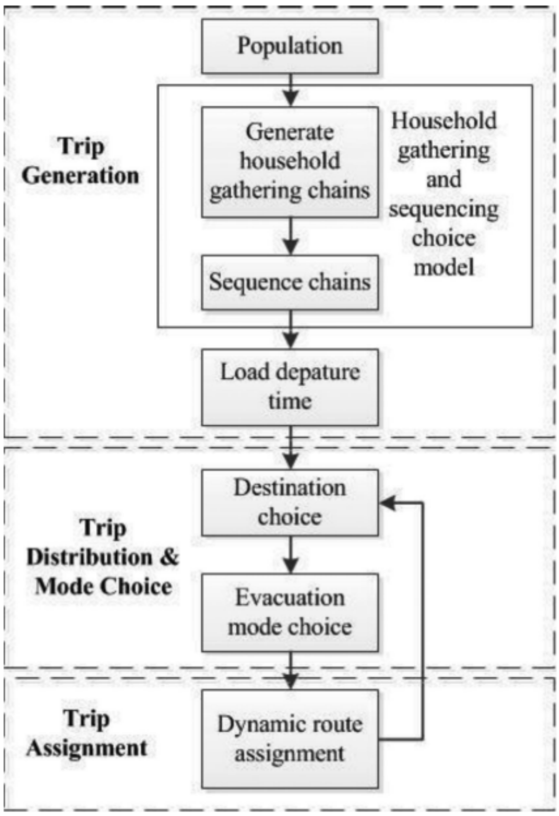

Figure 2.3: Framework of the evacuation model considering family gathering [30]

2.3. Evacuation Behaviour

In this section, evacuation behaviour in tsunamis or no-notice disasters are discussed focusing on empirical analyses. Some aiming for identifying factors that explain evacuation behaviour and the other developing choice models in which the identified factors are applied. The focus here is placed on the former, behavioural aspects rather than modelling techniques, which will be relevant in the data analysis presented in the next chapter. Starting from the evacuation behaviour analysed from the 2011 Tohoku tsunami are presented, some research dealing with other tsunami or hypothetical tsunami are provided as a complementary reference. And then, some studies particularly on family gathering activity are given emphasizing factors behind that behaviour.

The 2011 Tohoku tsunami

Different evacuation behaviours between the geography types, the plain area in the south and the ria coast area in the north, are revealed by Goto et al. [19] and Morita et al. [38]. They present that people in the ria coast area, Yamada, were more likely to evacuate on foot than those in the plain area, Ishinomaki. It is also probably because people in the ria coast could evacuate up to the nearby hills while people in the plain area had to travel away from the coast or to higher buildings/grounds, which is indicated also by Morita et al. [38]. In addition, Goto et al. [19] report that people in Yamada had a higher risk perception than people in Ishinamaki, presenting effects of the past experience in the 1960 Chile Earthquake Tsunami which hit Yamada. An evacuation choice model developed by Urata and Pel [65] using the suvery by MLIT shows that evacuation timing is affected by people's risk recognition which can be defined by risk education and information as well as socio-demographics. Okumura et al. [48] also develop an evacuation choice model considering risk perception defined by various factors such as tsunami alarm and evacuation call. They validate the model with the actual casualty rates between the two area, one close to the sea and the other away from the sea, assuming they have different risk perception. Effects of seawall on evacuation departure choice is revealed by Troncoso Parady et al. [61] who prove that a false sense of security deriving from the presence of seawalls can reduce the likelihood of prompt evacuation by 30%. Urata and Hato [64] construct a evacuation departure time model focusing on activities performed prior to evacuation. The survey data by MLIT in addition to the other evacuation survey pertaining to the same event was used for the estimation of the model parameters which indicate that those who participated activities such as supporting someone or gathering information tends to make the first trips faster but evacuate later than those who did not. Also, it is found that the distance to the sea, the gender, and cooperation behaviour are influential factors on the departure time choice. Troncoso Parady and Hato [60] identify factors that affect the destination choice by accounting for spatial correlation into the model specification. It is reported that OD distance by mode, OD altitude difference, number of buildings and number of officially designated shelters are statistically associated with the evacuation destination choice. Makinoshima et al. [34] developed a mode choice model using a similar type of data as the one by MLIT collected separately in Kesennuma with the aim of investigating opportunities to reduce the car usage. The resultant model indicates various factors associated with the car usage;gender, age, initial location, departure time, shelter type, and evacuation distance while the evacuation distance is considered a dominant factor for predicting the evacuation mode choice. It can be questioned, however, with respect to other factors associated with the car usage that car availability, which is not included in the model, could be identified behind those correlations.

Hypothetical or other tsunami

Fraser et al. [15] report, by conducting surveys in New Zealand based on a hypothetical local earthquake and tsunami, that female are more likely to evacuate from out-of-home locations such as a shopping area and male are more likely to evacuate from their home, and that older people are less likely to evacuate than younger one. Also, it suggests that a greater intention to evacuate when they were at the survey location than they did for an event occurring when they were at home. Charnkol and Tanaboriboon [7] present, by developing an evacuation choice model using survey data collected in Thailand based on a hypothetical tsunami, that disaster knowledge, distance to the sea, and the number of children in the household are associated with the evacuation choice. From a post-disaster survey conducted in American Samoa for the evacuees, Lindell et al. [27] reveals that warning messages were not significantly associated with the evacuation, arguing the widespread recognition of environmental cues such as the earthquake prompted the majority of the respondents evacuate before those messages were delivered. In addition, it shows that demographic characteristics such as age, gender, and martial status had few and inconsistent correlations with the evacuation.

Family gathering activity

With respect specifically to the family gathering activity, a number of literature pertaining to the 2011 Tohoku tusnami reports returning-home activities prior to their evacuation for the purpose of the family gathering or rescuing dependent family members. Yanagihara and Murakami [72] find that, in Ishinomaki, 25% of the respondents who evacuated by car returned home once and then evacuated, and Hara and Kuwahara [20] argue analyzing the probe data that there were people travelling even from one city to the neighbouring cities possibly in order to return home rather than self-evacuation given the road running in parallel with the coastal line. Murakami et al. [42] conclude that people who thought large tsunami would not come were more likely to be engaged in other activities before evacuation such as finding family members whereas Goto et al. [19] argue that young families tended to return home to rescue their elder parents. Other literature also reveals those behaviours during the event and claims the danger of delaying evacuation [6, 14, 56]. Moreover, the intentions to pick up family members are revealed by stated preference surveys assuming hypothetical tsunami scenarios [15, 54]. However, most of these literature does not analyse specifically the family gathering activity, not providing factors that affect that particular behaviour. An experimental study of post-earthquake travel behaviours in New Zealand, on the other hand, shows that about a half of the people has an intention to reunite with their family members to evacuate together, and that those who initially located at work are more likely to travel home to do so.[67]. Moreover, Liu et al. [29] investigate influential factors on that particular behaviour such as gender, car availability, and education, using the survey data collected in the Chicago metropolitan area. In-depth structured interviews were conducted for over 300 people to ascertain how people make family arrangements for picking up dependents under a normal weekday and two hypothetical no-notice events during the day. The result indicates that gender, car availability, distance between parents and children, ethnicity, income and parents employment status are considered influential factors. Using the same data, Liu et al. [31] explore family-gathering activities for non-children, i.e. spouses, parents, adult-age children, and even non-family members. In addition, whether family members reunite particularly at home for the evacuation is also investigated. It is found that car availability playing a dominant factor in gathering a spouse, family members more likely to gather at home if there are children under the age of 18 and greater numbers of adults in the household, while commute mode and car availability are not significantly associated with reuniting family members at home. It should be noted in respect of the survey that, although the hypothetical event is no-notice, an incident causing the evacuation is not specified in the survey. This might not be satisfactorily comparable with events like tsunami where the sense of danger people feel can be rather imminent.

Conclusion

Through this chapter, the following brief conclusions can be drawn. Each conclusion can be referred to the rest of this study.

- Activity Based Model would be the most suitable for evacuation modelling taking the family gathering activity into account to better predict the demand.
- Some choice models are likely to be simplified in evacuation modelling and more research tend to focus on the route choice modelling. (Chapter 4)
- For tsunami evacuation modelling, their focus is placed rather on methodological aspects leaving out behavioural aspects and there is no research dealing with the family gathering activity. (Chapter 3)
- The family gathering activity can be incorporated into the overall models in various ways. (Chapter 4)
- Socio-demographic variables such as gender and age pose indecisive conclusions regarding the effects on evacuation behaviour while the effect of risk perception and recognition seems conclusive. (Chapter 3)
- The family gathering activity during the the 2011 Tohoku tsunami appears to be well acknowledged but there has been no research to investigate the family gathering behaviour. (Chapter 3)
- Some factors that explain the family gathering behaviour have been identified; initial location, gender, car availability, distance between parents and children, ethnicity, income and parents employment status, children's age and numbers of adults in the households. (Chapter 3)

3

BEHAVIOURAL ANALYSIS

3.1. Methodology

Behavioural analysis is carried out in the step shown in Figure 3.1. Using the behavioral survey data collected after the 2011 Tohoku tsunami, travel patterns pertaining to the family gathering are investigated by statistical tests based on some hypotheses. Those hypotheses are to be formulated referring previous evacuation studies. The results of the tests would provide some insights into the family gathering activity during the evacuation. Although traditionally the data should be collected after formulating hypotheses to be tested for statistical analysis, this study has been initially motivated by the survey. Therefore, the hypotheses design is carried out in parallel with the data analysis, investigating what hypothesis can be formulated. This unconventional order should be compensated by sound argumentation for the hypothesis formulation.

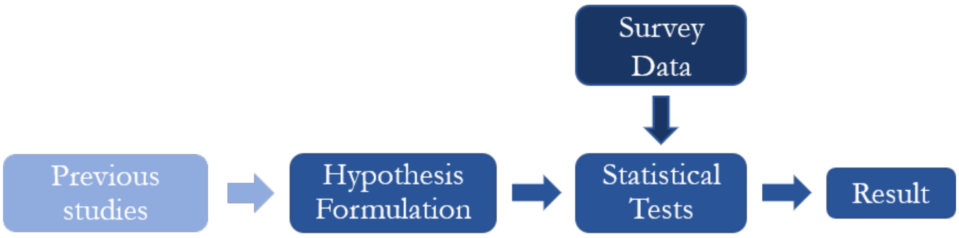

Figure 3.1: Methodology for behavioural analysis

3.2. Survey Data

Background

On Friday March 11, 2011, at 14:46 local time (06:46 CET), a magnitude-9.0 powerful earthquake occurred with the epicentre approximately 130 km (80 miles) east of the city of Sendai in Tōhoku, the northeastern region of Japan. The earthquake was the strongest earthquake ever recorded in Japan and caused a series of large tsunami waves reaching the coastal area of the region first around 20-25 minutes after the earthquake [14]. As a result of the whole event, 15,782 people died and 4086 people were missing as of September 11 the same year [23], most of which were caused by the tsunami rather than by the buildings collapsed. Nakahara and Ichikawa [47] show that more than half of the victims were 65 years or older, and that the older the people were the higher the fatality rates were. This indicates there were more elder people failing to evacuate from the tsunamis. And also they present that the fatality rates between male and female were not significantly different while that between the geographical features were significantly different. The coastal area can be characterized roughly by two types of geography; plain and ria. In the south, Fukushima and southern part of Miyagi, the coastal area is plain where the larger number of people live rather inland whereas in the north, Iwate and northern part of Miyagi, the coastal area is ria where the bays are narrow and shallow, and more people live near the sea or among steep terrains. The fatality rate in the ria area is almost twice as high as in the plain area [47].

Sample

During the survey conducted by MLIT from September and December 2011, individuals over 20 years old in 62 cities affected by the event were interviewed. The sampling was designed considering the 2010 population census to represent the population in terms of the gender and the age although the collected sample skews towards more women and more elder to some extent. For this study, five cities with a certain size of population and area are chosen from the plain area, Higashi matsushima (352), Ishinomaki (1280), Natori (404), Soma (255), and Minami soma (389), excluding some respondents (377) living in the ria area of Ishinomaki. The reasons for choosing cities only from the plain area are; firstly, the evacuation behaviour seems different between the plain and the ria area [19, 38], and secondly, research on the plain area, which is more widespread geographical feature overseas as well as in the country, could provide more generalizable knowledge since walking up to nearby hills, dealing with the mode choice and the destination choice, can not be an option in those plain areas.

The main component of the survey is the trip data answered by the respondents as to when, to where, by which modes, for what purposes they made trips up until the midnight on the day of the event. Since the focus of the current research is trips to evacuate from the tsunami and trips for family gathering before those evacuation, it is decided that all the trips begun after the arrival time of highest tsunamis defined by MLIT for each city, 15:20 in Higashi matsushima, 15:26 in Ishinomaki, 15:49 in Natori, 15:50 in Minami soma, 15:54 in Soma, are to be excluded. Besides, another decision was made with respect to the trip purpose that trips for both “Safety confirmation of family, relative, and friend” and “Searching for or gathering family, relative, and friend” are to be considered as the family gathering activity, which is the main interest of this study.

Socio-demographic and context attributes variables are presented in Table 3.1. In the dataset, same as the overall sample, there are more women than men and more elder than younger compared to the 2010 population census averaged only by the five cities in which 48% are men and 52% are women while 28.0% are 20-30, 32.4% are 40-50, and 39.8% are over 60. The dominance of family households against individual households should be noted as the census shows the family households account for 76.5%. Regarding the location at the time of the earthquake, more than half of respondents, 62.7%, were at home which might be explained by the respondent’s occupation where only 19.0% were engaged in full-time work.

Table 3.1: Socio-demographic and context attributes variables

Variable	Sample size	Categories	Percent
Gender	2680	1. Male	37.7%
		0. Female	62.3%
Age	2680	1. 20-39	20.5%
		2. 40-59	29.8%
		3. over 60	49.7%
Occupation	2659	1. Full-time (private)	17.3%
		2. Full-time (public)	1.7%
		3. Part-time or temporary	11.5%
		4. Self-employed	9.3%
		5. Forestry	2.7%
		6. Fishery	4.3%
		7. Student	0.7%
		8. Caregiver	14.6%
		9. Unemployed	36.9%
		10. Other	1.0%
Household type	2680	1. Family	93.6%
		0. Individual	6.4%
Children under elementary schools in the households	2680	1. Yes	24.9%
Family member above 70 in the households	2680	1. Yes	39.7%
City of residence		1. Higashi matsushima	13.1%
		2. Ishinomaki	47.8%
		3. Natori	15.1%
		4. Soma	9.5%
		5. Minami soma	14.5%
Risk perception	2675	1. Tsunami will come or may come	38.2%
		0. Tsunami won't come or didn't think of it	61.8%

3.3. Statistical Analyses Methods

Data processing

Some variables, mostly related to the travel choices, have been combined or recategorized in order to have a less number of categories, preparing for statistical analyses. As for “Destination for evacuation or gathering”, since there are many respondents choosing unidentified location, “Designated shelter” and “Other”, extra attention needed to be paid to text-based answers pertaining to the locations, to produce a couple of new categories such as “Shrines” and “On the road”. The variables that have been recategorized are found in Table 3.2. Besides, as a proximity of distance travelled by the respondents, euclidean distance between the departure locations and the destination locations have been calculated for the evacuation trips and the family gathering trips.

Table 3.2: Operationalization of categories

Variable	Category	New category
Occupation	1. Full-time (private)	1. Employed
	2. Full-time (public)	1. Employed
	3. Part-time or temporary	1. Employed
	4. Self-employed	1. Employed
	5. Forestry	1. Employed
	6. Fishery	1. Employed
	7. Student	3. Other
	8. Caregiver	2. Unemployed
	9. Unemployed	2. Unemployed
	10. Other	3. Other
Location at the time of the earthquake	1. Home or neibourhood	1. Home
	2. Home above the ground floor	1. Home
	3. Relative or friend's house	5. Other
	4. Work place	2. Work
	5. School	5. Other
	6. Shop	3. Shop
	7. High floor of previous location	5. Other
	8. Outside	4. Outside
	9. Ship on the sea	5. Other
	10. Tall building	5. Other
	11. High ground	5. Other
	12. Designated shelter	5. Other
	13. Other	5. Other
Mode for evacuation or gathering	1. Carried on someone's back	3. Walking or the other
	2. Walking alone	3. Walking or the other
	3. Walking with someone	3. Walking or the other
	4. Walking with child or eldery	3. Walking or the other
	5. Walking with mobility dependent	3. Walking or the other
	6. Cycling alone	3. Walking or the other
	7. Carried by bicycle	3. Walking or the other
	8. Motorbike alone	3. Walking or the other
	9. Carried by motorbike	3. Walking or the other
	10. Car	1. Driving
	11. Carried by car	2. Car passenger
	12. Other	3. Walking or the other
Destination for evacuation or gathering	1. Home or neighborhood	1. Home
	2. Home above the ground floor	1. Home
	3. Relative or friend's house	2. Someone's home
	4. Work place	10. Other
	5. School	3. School
	6. Shop	5. Private facilities
	7. High floor of previous location	7. Shrines
	8. Outside	8. On the road
	9. Ship on the sea	9. On the sea
	10. Tall building	see below
	11. High ground	6. Higher ground
	12. Designated shelter	see below
	13. Other	see below
	Buildings such as city halls, hospitals, and community centers are considered "4. Public facilities"	

Given the data processed, descriptive statistics for the travel choices is presented in Table 3.3. Less than half the respondents, 44.9%, made a trip for evacuation before the arrival of the highest tsunamis. The mean of the departure time for those evacuation trips is 15:07 while 52.5% of the evacuees left for evacuation before 15:00. The destinations for evacuation are varied among the evacuees. School turns out to be the most popular destination with 31.1% and the rest is spread out over various locations such as public or private facilities and higher ground. The public facilities refer to e.g. hospitals, city halls and community centers and the private facilities involve e.g. shopping malls and hotels. As for the modes used by the evacuees, 32.6% drove a car, 25.2% took a car ride together, and the rest, 42.1%, are dominantly walking with about 2% of bicycles and motorbikes included. Average euclidean distance travelled to reach the evacuation destination, including all the intermediate trips, is 1674m which differs without doubt greatly among the modes, 2715m for driving, 1871m for car passenger, and 753m for walking. With respect particularly to the family gathering, 19.1% of the respondents performed trips for that purpose and 75.0% of those trips began before 15:00 with mean time of 15:00. In contrast to the evacuation destination, the locations for the gathering are concentrated on three locations; home (42.6%), someone's home (16.8%), and school (26.5%). Regarding the modes for the gathering, driving accounts for almost double the share of the same mode for the evacuation trips while only 25.4% walked to do the family gathering. Average euclidean distance travelled to reach the gathering locations is 2933m consisting of 3606m for driving, 3684m for car passenger, and 926m for walking.

Table 3.3: Trip decision variables

Variable	**Sample size**	**Categories**	**Percent/Mean (Median)**
Initial location	2680	1. Home	62.7%
		2. Work	14.6%
		3. Shop	4.7%
		4. Outside	7.1%
		5. Other	6.8%
Evacuation	2680	1. Yes	44.9%
		0. No	55.1%
Departure time for evacuation	1204		15:07 (15:00)
Destination for evacuation	1198	1. Home	9.3%
		2. Someone's home	7.4%
		3. School	31.1%
		4. Public facilities	13.6%
		5. Private facilities	9.4%
		6. Higher ground	13.6%
		7. Shrines	4%
		8. On the road	2.1%
		9. On the sea	1.8%
		10. Other	7.5%
Mode for evacuation	1204	1. Driving	32.6%
		2. Car passgner	25.2%
		3. Walking or the other	42.1%
Euclidean distance to evacuate	1204		1676 (786)
Family gathering	2680	1. Yes	19.1%
		0. No	80.9%
Departure time for family gathering	510		15:00 (15:00)
Family gathering location	509	1. Home	42.6%
		2. Someone's home	16.9%
		3. School	26.5%
		4. Public facilities	2.4%
		5. Private facilities	2.9%
		6. Higher ground	1.2%
		7. Shrines	0.4%
		8. On the road	5.5%
		9. On the sea	0.2%
		10. Other	1.4%
Mode for family gathering	511	1. Driving	63.0%
		2. Riding	11.5%
		3. Walking or the other	25.4%
Euclidean distance to gather family	511		2933 (1491)

Type of travellers

In order to investigate the family gathering behaviour and separate travellers who did not have choices for family gathering in the first place, four type of evacuees are defined depending on the household type and whether they performed the family gathering or not. The four types of travellers are explained below and examples of those travellers are illustrated in Figure 3.2.

Type I: Family households with the family gathering (Fw/G)

They live with other family members such as a spouse, children, and parents, and made a trip to gather with some of those members.

Type II: Family households without the family gathering (Fw/oG)

They live with other family members such as a spouse, children, and parents, but did not make a trip to gather with any of those members.

Type III: Individual households with the family gathering (Iw/G)

They live on their own but made a trip to gather with family members living in nearby places.

Type IV: Individual households without the family gathering (Iw/oG)

They live on their own and did not make a trip to gather with family members living in nearby places or did not have such a family member.

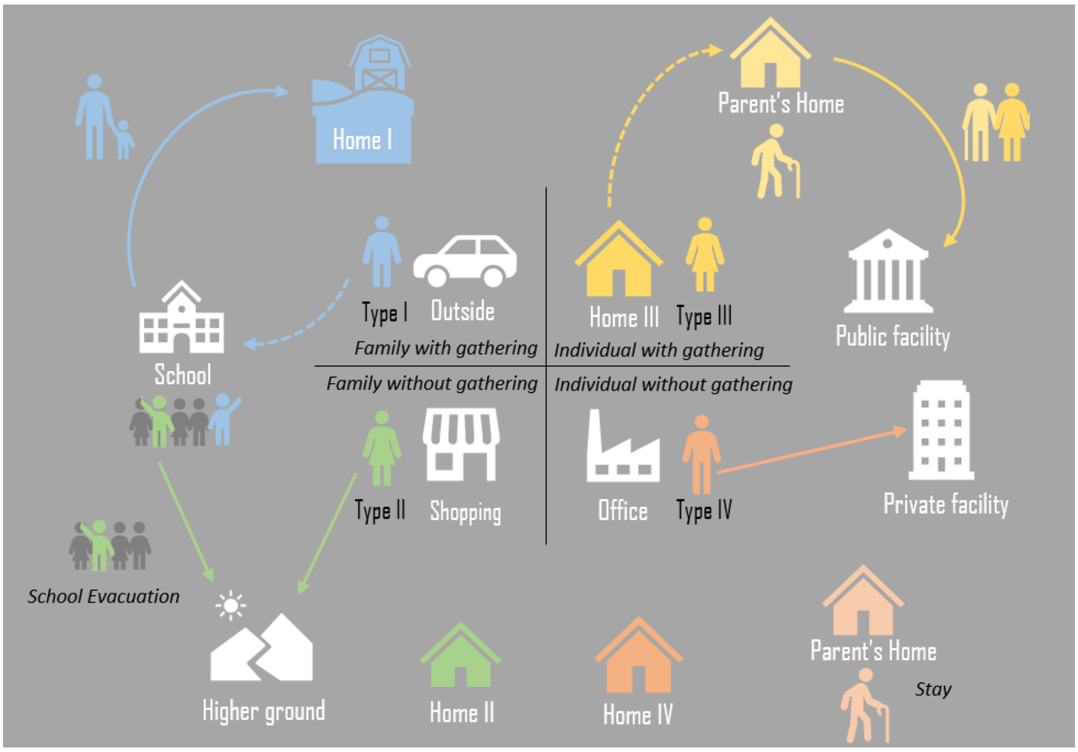

Figure 3.2: Four types of travellers

Statistical tests

Chi-squared test

Chi-square tests evaluate if two categorical variables are associated by showing contingency tables of those variables. It calculates $\tilde{\chi}2$ using observed counts and expected counts, which would be larger if the two variables are not independent, meaning there is an association between the two variables. The null hypothesis for this test is set as;

There is no association between two variables.

This null hypothesis can be rejected when $\tilde{\chi}2$ is large enough, depending on the level of significance, to claim that the difference between the expected count and the observed count does not occur only by chance and thus these are associated. There are two assumptions that need to be met in order to perform the test as follows;

1. Observations are independent such that categorical variables are not "paired" in any way (e.g. pre-test/post-test observations)
2. Sample sizes are large enough that not more than 20% of the contingency cells having expected values < 5

In case of this study, the first assumption can be met because the observations are individual persons. The second assumption, however, may not be met depending on variables and categories to be chosen which may make the sample sizes too small. For the valid cases, Chi-squared test is to be applied to test if there is an association between two variables.

Mann-Whitney U test

Mann-Whitney U test can be used to determine whether there are differences in the distributions of continuous variables for two groups. Unlike independent t-test, it is a non-parametric test not assuming normal distribution. Therefore, instead of comparing mean of two groups, it works by ranking each score of the continuous variable which are averaged leading to mean rank. The null hypothesis for this test is as follows;

The distribution of scores for the two groups are equal

This null hypothesis can be rejected when difference of the mean rank is large enough to claim that the difference does not occur only by chance thus the distribution are not equal. There is only one assumption below for this test apart from the type of variables where one should be continuous or ordinal and the other has to be categorical.

1. Observations are independent such that there must be different participants in each group with no participant being in more than one group.

This assumption can be met for this study same as Chi-square test. Thus, Mann-Whitney U test is to be applied to test if the departure time distribution for the evacuation and the family gathering are statistically different from each other.

Hypothesis formulation

In this section, associations between some variables with the family gathering are discussed, and various hypotheses are formulated based on previous studies and expert's judgement. For the travel choices, namely leave/stay choice, departure time choice, destination choice, and mode choice, contingency tables for those choices and the type of travellers are presented discussing some patterns. And then, referring previous studies if available, hypotheses are presented. Regarding socio-demographic and context attributes such as gender and age, associations between those attributes and the travellers in family households (Fw/G & Fw/oG) are discussed, formulating some hypotheses. All the hypotheses are tested and presented in the following section.

Leave / Stay choice

There has been no studies discussing an association between leave / stay choice for evacuation and leave / stay choice family gathering, and it seems difficult to make an argument over it as these two decisions can be made interchangeably. Someone deciding to gather with their family but not to evacuate may change their idea after the gathering since the family member urge them to evacuate, or the other way around that their decision to evacuate can be overturned. I would argue, however, that people gathering with families are less likely to evacuate for two reasons. First, people would feel relieved by gathering with families and this sense of relief could in turn lower the sense of danger or risk awareness, making them to stay where they gather. Second, it seems that people having tsunami risk perception do not travel to gather with families but evacuate directly since a danger of tsunami can be imminent. People who performed the family gathering are therefore assumed less likely to have had an intention to evacuate from tsunami. Table 3.4 seems to indicate that possibility. Evacuation rate for both family households and individual households with family gathering is lower than their counterparts. Therefore, the following hypothesis is formulated;

> **H1 (Evacuation choice)**: People who performed the family gathering were less likely to evacuate.

Table 3.4: Evacuation choice by types of travellers

	Evacuation		
	Yes	No	Total
Family with gathering	143	343	486
	29.4%	70.6%	100%
Family without gathering	969	1054	2023
	47.9%	52.1%	100%
Individual with gathering	8	17	25
	32.0%	68.0%	100%
Individual without gathering	84	62	146
	57.5%	42.5%	100%
Total	1204	1476	2680
	44.9%	55.1%	100%

Departure time choice

Contrary to the evacuation choice, a certain level of difference in the departure time choice between those who performed the family gathering and those who did not is expected because those who did not include people evacuating without performing any activities and thus the departure time tends to be earlier. Table 3.5 shows that the departure time for both Fw/oG and Iw/oG was 10 minutes earlier in average than that for Fw/G, and that both mean and median of the departure time for Fw/oG & Iw/oG are the same. Looking at the probability distribution in Figure 3.3, those two groups without the family gathering present similar shape of distribution where there is a sharp rise around 15:00. On the other hand, despite the fact that the sample size for Iw/G is considerably small, the shape of distribution for the two groups with the family gathering are clearly distinct from the other two. This is hardly surprising as the evacuation departure time for the groups with the family gathering is largely defined by the travel time of previous trips for the family gathering.

Table 3.5: Mean and median of the evacuation departure time for four types of travellers

	N	Mean	Median
Family with gathering	143	15:15	15:15
Family without gathering	969	15:05	15:00
Individual with gathering	8	15:09	15:06
Individual without gathering	84	15:05	15:00
Total	1204	15:07	15:00

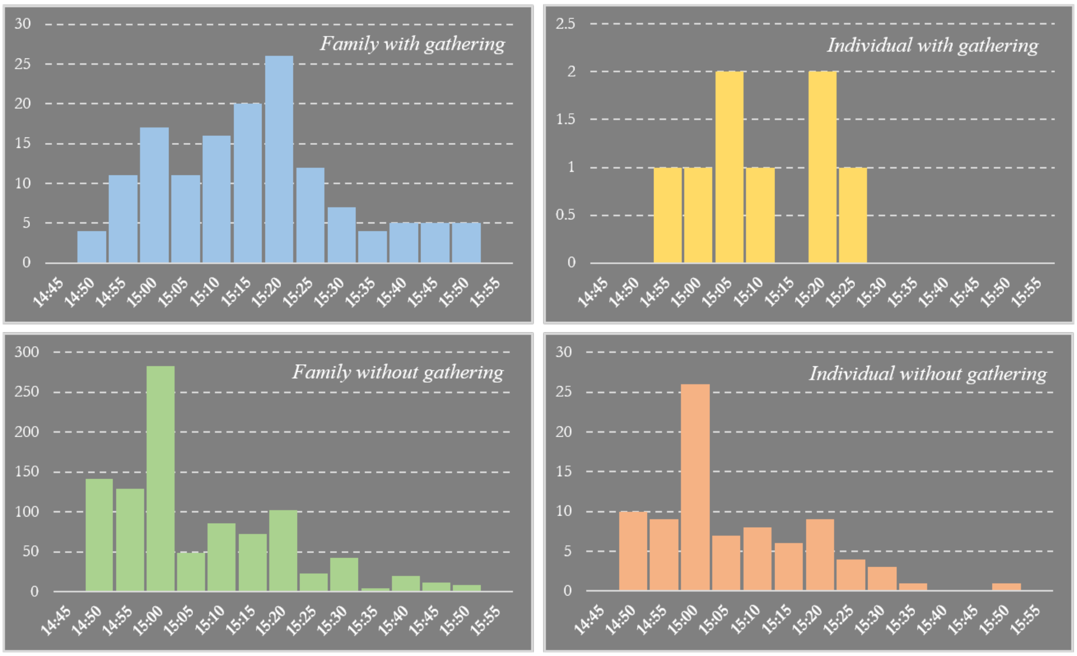

Figure 3.3: Histogram of the departure time choice for the evacuation trips (x axis for time, y axis for counts)

To look further into the departure time, the departure time for the family gathering trips, instead of the departure time for the evacuation trips, is presented in Table 3.4. It presents different shape of distribution compared to that of the two groups not performing the family gathering. As for the departure time for the family gathering trips, the biggest rise is found right after the earthquake, and nearly 75% of people left for the family gathering by around 15:00 whereas less than 60% of people did so in the same time for the evacuation. From this difference, a hypothesis is formulated as below.

H2 (Departure time choice): Departure time distribution for the evacuation trips and the family gathering trips are significantly different.

This hypothesis can be tested by Mann-Whitney U test where the distribution of the departure time for the family gathering and the distribution of the departure time for the evacuation are compared. Due to the small sample size for people in individual households, the test is performed only for people in family households.

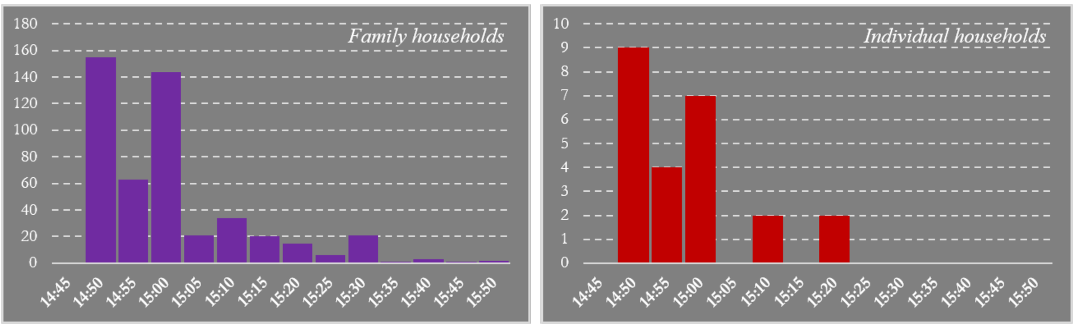

Figure 3.4: Histogram of the departure time choice for the family gathering trips (x axis for time, y axis for counts)

Evacuation destination choice

As shown in Table 3.6, due to the various destination types, it is challenging to discuss something out of this statistics. The most frequent destination for all the travellers is "School" while the second place comes with different locations depending on the type of travellers. One thing that should be noted from this table is the fact that nearly half Fw/oG evacuated to either "Home", "Someone's home", and "School", while only 40% of Fw/G chose those locations. This might be in part because of the experimental set-up of the survey where trips for evacuation and gathering were treated separately although those could be achieved in the same trip. It can be said that the gathering locations are safe enough for tsunami so that they did not have to evacuate further, leading to the lower rate for those locations to be given as evacuation locations. In fact, 42.6% of the family gathering location is "Home" and 65.4% of those people did not evacuate after the gathering. In terms of hypothesis formulation, considering this ambiguity and no previous studies on an association between the two choices, no hypothesis can be formulated for this choice.

Table 3.6: Destination choice by types of travellers

	Home	Someone's home	School	Public facil.	Private facil.	Higher ground	Shrine	Road	Sea	Other	Total
Family with gathering	7 5.0%	14 9.9%	36 25.5%	15 10.6%	16 11.3%	28 19.9%	6 4.3%	4 2.8%	1 0.7%	14 9.9%	141 100%
Family without gathering	96 9.9%	71 7.4%	308 31.9%	131 13.6%	92 9.5%	123 12.7%	40 4.1%	17 1.8%	21 2.2%	66 6.8%	965 100%
Individual with gathering	0 0%	1 12.5%	4 50.0%	1 12.5%	0 0%	0 0%	0 0%	1 12.5%	0 0%	1 12.5%	8 100%
Individual without gathering	9 10.7%	3 3.6%	25 29.8%	16 19.0%	5 6.0%	12 14.3%	2 2.4%	3 3.6%	0 0%	9 10.7%	84 100%
Total	112 9.3%	89 7.4%	373 31.1%	163 13.6%	113 9.4%	163 13.6%	48 4.0%	25 2.1%	22 1.8%	90 7.5%	1198 100%

Evacuation mode choice

Table 3.7 shows that "Walking and etc" is the most popular mode used by the travellers except Fw/G where the share of "Driving" in Fw/G stands out with 49.7%. This is consistent with findings by Liu et al. [29] [31] reporting that car availability is the dominating factor in picking up child and gathering a spouse. It also seems reasonable for those people to use cars if those people gather with someone dependent in terms of mobility such as children and elder people. To investigate the association between the mode choice and the family gathering, a hypothesis is formulated as follows;

> **H3 (Mode choice)**: Those who performed the family gathering were more likely to evacuate by car than those who evacuated without family gathering.

Table 3.7: Mode choice by types of travellers

	Driving	Car passenger	Walking and etc	Total
Family with gathering	71	21	51	143
	49.7%	14.7%	35.7%	100%
Family without gathering	305	252	412	969
	31.5%	26.0%	42.5%	100%
Individual household with gathering	1	2	5	8
	12.5%	25.0%	62.5%	100%
Individual without gathering	16	29	39	84
	19.0%	34.5%	46.4%	100%
Total	393	304	507	1204
	32.6%	25.2%	42.1%	100%

Initial location

Based on an experimental investigation of post-earthquake travel behaviour in which people are set to encounter earthquake either at “Home” or “Work”, Walton and Lamb [67] conclude that the majority of trips from “Work” choose “Home” out of seven destinations such as “School” and “Another person’s house”. In addition, the majority of those trips to “Home” were to reunite with friends or family. On the other hand, more than half the people initially at “Home” did not travel. From these findings, it can be assumed that the initial location affects the decision about the family gathering, leading to the first hypothesis;

> **H4 (Initial location 1)**: People initially at “Work” were more likely to perform the family gathering than people initially at “Home”.

Moreover, I would argue that people initially at less familiar places may be tempted to perform the family gathering compared to well familiar places such as “Home” and “Work” because people can feel more uneasy at less familiar places than at well familiar places, desiring to gather with someone familiar to feel relieved. Thus, a hypothesis can be formulated considering “Shops” and “Outside” as less familiar places;

> **H5 (Initial location 2**: People initially at “Shops” or “Outside” were more likely to perform the family gathering than people initially at “Work”.

Gender

There has been two studies, using the same data set, on gender as a factor for family gathering behaviour. Liu et al. [29] report that women are more likely to be responsible for picking up a child in a normal condition and this also holds true in an evacuation condition. Liu et al. [31] conclude that gender is not significantly associated with the gathering with their spouse, and that gender is, however, associated with the gathering locations, claiming that women are less likely to gather with family members at home than men. In the data set of this study, there is no information as to with whom they gathered by the trips for family gathering, thus child pick-up can be assumed if the family gathering location is "School". Besides, unlike the data set used by those previous studies where only parents are considered, the data set of this study does not specify it. Hence, people at younger age having children under elementary school in their households are assumed to be parents. Also, due to the small sample size of people at 20-39, 40-59 are also included in this test. Then, a hypothesis is formulated focusing on two locations for the family gathering location as follows;

> **H6 (Gender)**: Women at 20-59 having children were more likely to travel to "School" compared to "Home" for the family gathering than men in the same condition.

Employability

According to Liu et al. [29], unemployed parents are more likely responsible for picking up children than employed parents under emergencies. The authors argue unemployed parents, including caregivers, are more likely to be at home and public schools are typically located within walking distance from home, thus they tend to do so. The same can be assumed for the five cities of Japan. However, the data set of this study provides whether the respondent have children under elementary school in their households but does not tell if they are their parents or not. Thus similar conditions need to be assumed by limiting the data to people at "20-39 yrs" having children under elementary school in their households. In addition, people at "40-59 yrs" in the same condition need to be included due to the sample size constraint. Then, the following hypothesis can be documented;

> **H7 (Employability)**: Unemployed people in 20-59 were more likely to go to "School" for the gathering location than employed people.

To test this hypothesis, two Chi-square tests are performed for "Employability" and "Family gathering locations". One compares "School" to "Home", and the other compares "School" to "Someone's home".

Age

Goto et al. [19] argue that during the 2011 Tohoku tsunami young families went back home to pick up their parents before their evacuation and some failed to evacuate. Considering also the fact that the fatality rate of elder people were higher than younger people because more elder people did not or could not evacuate ([47], [73]), it seems reasonable to assume that more young people gathered with their parents to take them to evacuate. Hence, the following hypothesis is formulated;

> **H8 (Age)**: Younger people having elder person in their households were more likely to perform the family gathering than elder people having elder person in their households.

To test this hypothesis, the data used needs to be limited to people having family members above 70 in their households. Also, there are three age categories in the data set, thus chi-square test is first performed for “20-39 yrs” and “above 40 yrs”, and then “20-59 yrs” and above “above 60 yrs” to check significant difference between those two groups.

3.4. Result

The results for the hypothesis testings are presented and discussed in this section. As for the travel choices, chi-square tests for, if sample sizes allows, four combinations of two types of travellers are presented. With respect to the socio-demographic and context attributes, contingency tables and $\tilde{\chi}2$ are provided. The significance of the results is also given in “$\tilde{\chi}2$” column of each table flagged with “***” for p-value less than 0.001, “**” for p-value less than 0.01, “*” for p-value less than 0.05, and “ns” (not significant) otherwise.

Travel choices

Leave / Stay choice

Table 3.8 shows that the null hypotheses for Fw/G & Fw/oG and Iw/G & Iw/oG are rejected with p-value less than 0.001 and 0.05, supporting H1 (Evacuation choice). For some reasons, people tend to not evacuate after the family gathering. Nevertheless, as discussed in the section of destination choice, we have to bear in mind that this result might be caused in part by the survey design; the reason why people who performed the family gathering did not evacuate is the family gathering locations were safe enough from tsunami so that they did not have to evacuate further. Another noteworthy result is found in the Chi-square test Fw/oG & Iw/oG. It statistically proves with p-value=0.024 that, irrespective of whether they performed the family gathering or not, people in individual households are slightly more likely to evacuate than people in family households. This does not hold true, however, for Fw/G & Iw/G who present a similar pattern in their evacuation choice.

Table 3.8: Chi-square test for evacuation choice

	$\tilde{\chi}^2$	degree of freedom	p-value
Family with gathering & Family without gathering	54.20	1	0.000
Individual with gathering & Individual without gathering	5.60	1	0.018
Family with gathering & Individual with gathering	0.076	1	0.783
Family without gathering & Individual without gathering	5.061	1	0.024

Evacuation departure time choice

Table 3.9 shows the null hypothesis is rejected with p-value less than 0.001, supporting H2 (Departure time choice). This is probably because of the early part of departure time, indicating that people needed more time to perform the evacuation compared to the family gathering as evacuation is assumed more likely to require some preparation or some time to decide on where to go.

Table 3.9: Mann-Whitney U test for departure time choice

	mean rank	u-value	p-value
The evacuation departure time	792.01	173443.00	0.000
The family gathering departure time	600.38		

Evacuation mode choice

As shown in Table 3.10, Chi-square test for Fw/G and Fw/oG rejects the null hypothesis with p-value=0.000 indicating that there is an association between the mode choice and the family gathering choice. Considering the higher percentage of car for those who performed the family gathering, H3 (Mode choice) is successfully supported. Furthermore, the Chi-square test Fw/oG & Iw/oG indicates a significant association between the household types and the mode with p-value=0.043. People in family households are more likely to drive a car than people in individual households. This seems to be explained by the fact about car availability, according to national statistics of Japan, car ownership for households with more than two persons is higher in all ages than in individual households.

Table 3.10: Chi-square test for mode choice

	$\tilde{\chi}^2$	degree of freedom	p-value
Family with gathering & Family without gathering	20.08	2	0.000
Individual with gathering & Individual without gathering	-	-	-
Family with gathering & Individual with gathering	-	-	-
Family without gathering & Individual without gathering	6.29	2	0.043

Socio-demographic and context attributes

Initial location

As shown in Table 3.11, the null hypothesis that there is no association between those two initial location and the choice of the family gathering is rejected with p=value less than 0.001. Looking at the percentage, it indicates that people at “Work” are more likely to perform the family gathering than people at “Home”, supporting H4 (Initial location 1). H5 (Initial location 2) is also supported by the test result as presented in Table 3.12 rejecting the null hypothesis with p=value less than 0.001. From those two results, it seems that the more familiar places people were in the face of the earthquake less likely to perform the family gathering.

Table 3.11: Initial location of travellers for family households

	Family gathering			
	Yes	No	Total	$\tilde{\chi}^2$
Home	172	1405	1577	**80.17*** **
	61.6%	84.3%	81.1%	
Work	107	261	368	
	38.4%	15.7%	18.9%	
Total	279	1666	1945	
	100%	100%	100%	

Table 3.12: Initial location of travellers for family households

	Family gathering Yes	No	Total	$\tilde{\chi}^2$
Work	107	261	368	**12.94*** **
	46.5%	61.1%	56%	
Shop & Outside	123	166	289	
	53.5%	38.9%	44%	
Total	230	427	657	
	100%	100%	100%	

Gender

Table 3.13 presents the result that rejects the null hypothesis with p=value less than 0.05. The percentage indicates that women are more likely to go to "School" while men are more likely to go to "Home" for the family gathering, supporting H6 (Gender).

Table 3.13: Gender of travellers for family gathering locations

	Home	School	Total	$\tilde{\chi}^2$
Male	19	11	30	**5.41** *
	38.8%	18.6%	27.8%	
Female	30	48	78	
	61.2%	81.4%	72.2%	
Total	49	59	108	
	100%	100%	100%	

Employability

Tables 3.14 shows that both tests fail to reject the null hypotheses with p=value larger than 0.05. Therefore, H7 (Employability) is not supported. This might be caused by the travelling distances which are considered different between the five cities and Chicago in which the previous studied conducted. Compared to the mega city like Chicago, people in the five cities are assumed to travel for work in shorter distance. Therefore, the distance to "School" from "Employed" people's location did not have an effect on picking up child.

Table 3.14: Employability of travellers for family gathering locations

	Home	School	Total	$\tilde{\chi}^2$	Someone's home	School	Total	$\tilde{\chi}^2$
Employed	45	46	91	**2.50^{ns}**	10	46	56	**0.11^{ns}**
	72.6%	59.7%	65.5%		55.6%	59.7%	58.9%	
Unemployed	17	31	48		8	31	39	
	27.4%	40.3%	34.5%		44.4%	40.3%	41.1%	
Total	62	77	139		18	77	95	
	100%	100%	100%		100%	100%	100%	

Age

The null hypothesis for the two tests is rejected with p-value less than 0.01 for "20-39 yrs" and "above 40 yrs" and less than 0.05 for "20-59 yrs" and "above 60 yrs" as shown in Table 3.15. Looking at the percentage, it shows that the older people were less likely to perform the family gathering compared to younger people. Assuming those family gatherings were for pick up elder family members, this might indicate that elder people living with partners aged above 70 were more likely to be gathered by children rather than their elder partners.

Table 3.15: Age of travellers for family households having elder person in their households

	Family gathering					Family gathering			
	Yes	No	Total	$\tilde{\chi}^2$		Yes	No	Total	$\tilde{\chi}^2$
20-39 yrs	47	122	169	**6.70****	20-59 yrs	116	380	496	**5.00***
	22.2%	14.8%	16.3%			54.7%	46.1%	47.9%	
above 40 yrs	165	702	867		above 60 yrs	96	444	540	
	77.8%	85.2%	83.7%			45.3%	53.9%	52.1%	
Total	212	824	1036		Total	212	824	1036	
	100%	100%	100%			100%	100%	100%	

Conclusion and discussion

In this chapter, the evacuation behaviour during the event is analyzed by testing the eight hypotheses. Despite the fact that most of the bases on which those hypotheses are formulated have different conditions in terms of e.g.survey design and hazard types, 7 hypotheses have been proved offering new insights into the gathering behaviour during the evacuation.

Regarding the evacuation choices, it has been found that “Stay / Leave choice” for the family gathering have associations with “Stay / Leave choice” and “Mode choice” for evacuation, and that “Departure time choice” for the family gathering and the evacuation shows significantly different patterns. People performing the family gathering were less likely to perform the evacuation, and if evacuate, they were more likely to use a car than those who did not perform the family gathering. In respect to the departure time choice, more people who performed the family gathering departed their initial locations right after the earthquake while more people who directly evacuated without family gathering departed their initial locations some time after the earthquake. These findings should be incorporated in the model since it changes the number of trips over time by vehicles.

As a discussion, some of these findings here seems to indicate that a decision on family gathering can be independent from a decision on evacuation, meaning that there seemed to be many people travelled to gather with family members without thinking of evacuation. In addition to the discussion in the section of “Stay / Leave choice” where the association between the evacuation choice and the family gathering choice can be explained by the gathering location being safe, the departure time choice also appears to indicate this possibility. If people considered to evacuate prior to the family gathering trips, the departure time for evacuation could look more similar since making a decision or taking an action for evacuation seems to take some time. Also, the destination choice for evacuation and family gathering seems to indicate there were people who did not evacuate after the family gathering because the gathering locations were the evacuation location at the same time. In this view, family gathering activities should not be considered as a part of chained trips of evacuation, but it is also possible to consider that people make two independent decisions in case of travel behaviour faced by earthquake and tsunami.

Lack of information in the data set as to who was having a car available at the time of the event and the distance not travelled to gather family members poses challenges to firmly interpret the result. As shown in the section of “Mode choice”, more people chose to drive for the family gathering than the evacuation, presenting an association between the two choices.

However, the causal direction for those choices are hardly determined because of the lack of data. More people might have performed the family gathering if they had a car available or the distance to gather family members were close enough to walk. Thus, having only a choice of walking or the long distance might have led to the choice of not performing the family gathering. Car availability also could be causing spurious effects on the proved association between the choice of family gathering and the socio-demographic / context attributes. Initial location, for instance, might have an association with car availability, and the reason that people initially at “Shop & Outside” performed the family gathering is because they were more likely to have a car available. Nevertheless, the effect of familiarity of locations on the choice of family gathering still seems plausible, and thus this association could be incorporated into the simulation. With respect to the association between the gender and the gathering location, the supported hypothesis is based on the two gathering locations while there are ten locations to have been chosen. It might be difficult therefore to incorporate this restricted association into the simulation. The association between the age and the choice of family gathering, on the other hand, could be applied into the simulation as the propensity of performing the family gathering is negatively associated with all the age groups.

4

MODEL FORMULATION

4.1. Methodology

This chapter describes a methodology of how the family gathering behaviour studied in the previous chapter can be modelled. To this end, a case study location is chosen from the five cities for which the data is used in Chapter 3. The case study location needs to be decided first because a part of population synthesis is case-specific . First, the description of the case study location is provided as well as some definitions applied in the model formulation. And then, population synthesis is presented in which household attributes and individual attributes are discussed separately. The following section is given to explain choice modelling as to how the result of behavioural analysis can be modelled using the synthesized population. In order to check its applicability, a simulation is carried out using the model, discussing the result in the forth section. In the fifth section, the validity of the simulation result is discussed, which is followed by the final section where conclusions and discussions are provided.

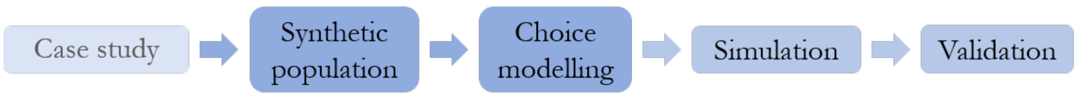

Figure 4.1: Methodology for model formulation

4.2. Case study location

Natori city is situated about 10 km down in the south of Sendai, which is the largest city in the Tohoku region (Figure 4.2). For this reason, the city has a Sendai International Airport where many people headed for to evacuate from the tsunamis on the day of the event. The airport was, however, also subject to be inundated. As shown in Figure 4.2, although the elevated national highway running through the city stopped the tsunamis flowing to some extent, the tsunamis reached up to 5.5 km from the coastal line, inundating approximately 28% of the municipal district. Although there was more than an hour for the first tsunami to reach the city, 922 people died mostly from the tsunamis, many of which occurred in Yuriage district, the area completely destroyed (Figure 4.3). Murakami et al. [42] report that the human loss was aggravated by some failures; the hazard map established in 2001 had assumed 1, 2 and 4 m height of tsunamis while the actual tsunamis exceeded 8 m, and tsunami warning and evacuation order was not broadcast through loudspeakers due to the dysfunction of the municipal wireless system, among others.

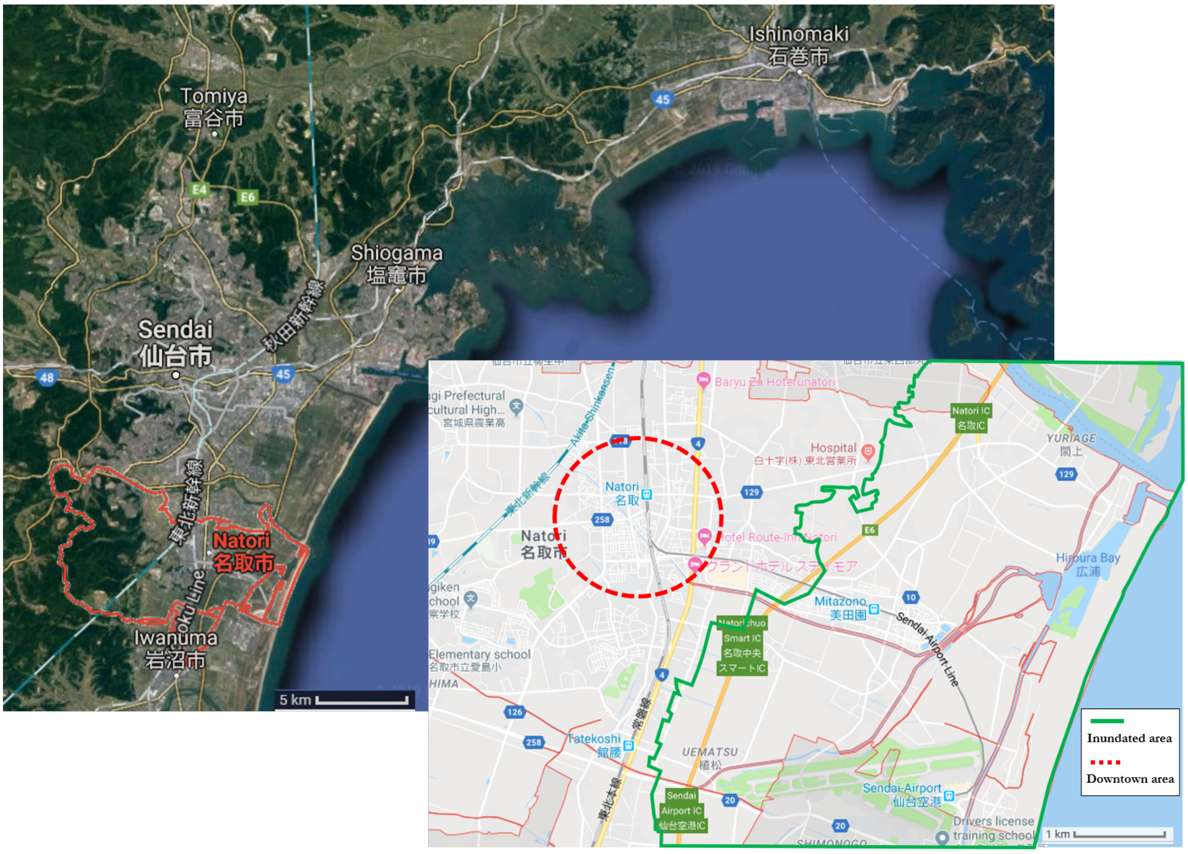

Figure 4.2: Location and inundation map of Natori city (Google map)

Figure 4.3: Before and after the tsunamis in Yuriage district (Natori city)

Area definition

In transportation demand modelling for urban-scale location, geographical features are aggregated rather than taking every single buildings into account in order to reduce a computational burden. According to the population census 2010, there were 251 districts defined by the address name in Natori. Out of those districts, firstly, mountainous area far from the coastal line has been excluded as the distance from the coastal line keeps the areas to be safe from tsunamis. Secondly, for a geographical aggregation, some districts have been combined to define areas having centroids where agents are to depart and arrive in the simulation. The aggregation has been made considering the transport network and the land use to ensure that it does not cause major discrepancies from what could happen. As a result, the number of areas becomes 31, which will be shown in the following section.

Transportation network

Out of the transport network which were present before the event in the defined area, three kinds of vehicle road types are defined for this study. The first one is “Arterial road” which is applied only for National Route 4 running north and south through the city, and the second one is “Local road” where two directions are clearly separated. The last one, “Shortcut”, is added around the downtown area and the centroids where congestion is expected in order not to underestimate the capacity. Although there are medias reporting there were people stepping up to the highway known as Sendai-Tōbu Road, the highway is to be excluded since more focus is on trip by vehicles. It seems reasonable to do so considering the configuration running parallel to the coastal line being at risk of inundation. With respect to the pedestrian network, all the vehicle roads involved have separated pedestrian streets. In addition to these streets, some streets used only by pedestrians are added as the vehicle road network is too coarse for walking speed that making a detour causes excess travel time. These transport network is presented in Figure 4.4

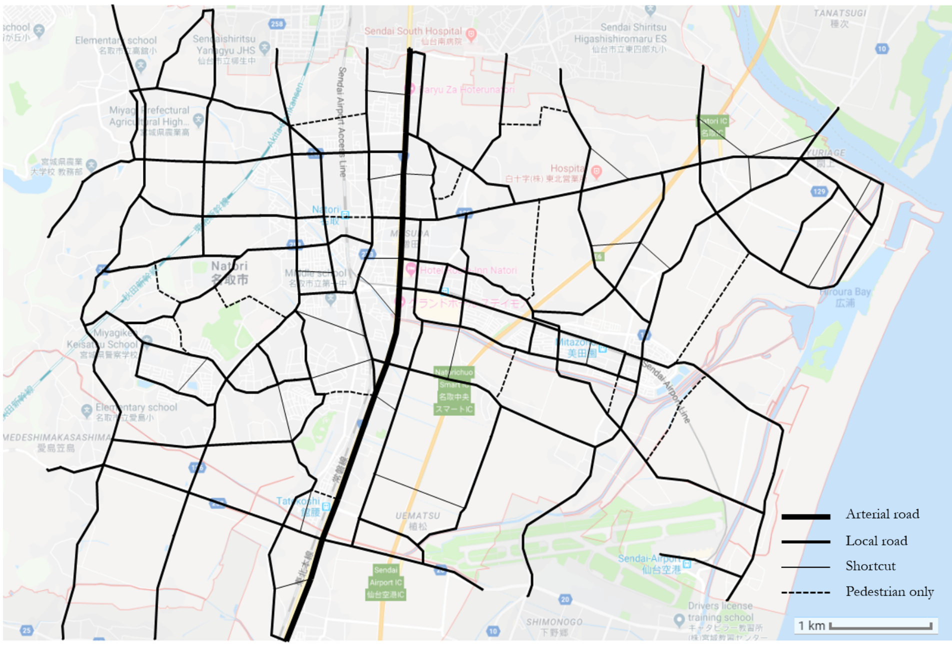

Figure 4.4: Transport network for the simulation (Google map

4.3. Synthetic population

In order to perform the simulation using the activity-based model, a synthetic population needs to be generated. Synthetic population represents individual agents modelled by the simulation, and thus should be similar to the actual population in the area. Attributes required to be included in population synthesis depend on the model specification. For the current model, the attributes that should be in the population synthesis are; residential location, age, the number of household members, and someone’s home for household attributes, and a decision-maker, working location, discretionary location, and initial location for individual attributes.

Household attributes

“Residential location” for households has been gained in the household census 2010 for the defined areas. With respect to “the number of household members”, since the household census 2010 does not provide the number of persons in their households, household composition needs to be assumed. Using some available information in the census, three kinds of household composition have been defined by assuming the number of persons in different household types. Households of nuclear families are assumed to have two persons while households of single person is treated as it is. Other types of households in the census are assumed to have four persons. The number of each household type can be identified, thus the number of each household composition for each area has been defined while keeping the number of households for each area at it is in the census (Appendix A.1).

With regard to “Age” the household census does not provide, the population census needs to be referred where the ratio of people in 20-39 and people over 40 for each area can be gained. People under 20 years old are excluded in the synthetic population since the survey by MLIT did not include those people and most of them are considered to have been at school at the time of the earthquake and stayed in there, affecting less on the evacuation traffic. The share of those two age groups are used to define the number of households for each age group per area and household composition by multiplication.

As for “Someone’s home” referring relative or friend’s home in the survey where people used as a gathering location as well as an evacuation location, due to the lack of data, a pair of households are randomly generated for all the households assuming they are relative or friends.

Individual attributes

The synthesized number of individual has been defined simply using “the number of household members” previously defined for each household, leading to 41951 individuals in total. All the household members are assumed to be the same age as there is no information about it. And then, individuals with the smallest id in each household has been assigned a decision-maker. For the sake of the simplicity, it has been assumed that household members are to follow decisions made by those decision-makers in case of a joint decision-making such as family gathering, even though in reality there could be some interactions of decision-making between household members.

In order to define “Initial location” being considered for “Leave / Stay choice”, two locations in the choice frequency need to be defined in addition to “Residential location”. “Work” is defined as “Working location” while “Shop/Outside” is defined as “Discretionary location” by assuming that people were on shopping or on the way to do some discretionary jobs. Despite the fact that it is not always right to assume every adult in the city have a job or certain places to shop, it has been decided, given the data available, that both “Working location” and “Discretionary location” are assigned to every individual like “Residential location”, and the share of initial location gained from the survey are applied into whole synthetic population to define the locations where people were present in the face of the earthquake. “Working location” is randomly assigned based on the ratio of the number of employees for each area against the total number of employees in the area using the economic census 2009. In some cases, the data is more aggregate than the data in the population census. In that case, the number of employees for disaggregated areas is calculated by multiplying the number of employees for the aggregated areas by the ratio of the area size of the disaggregated areas against the area size of the aggregated areas. Using the same data as “Working location”, “Discretionary location” is randomly assigned based on the ratio of the number of businesses registered as certain industries for each area against the total number of those businesses in the whole area. Out of 19 industries (A-S) categorised in the census, (I)Wholesale/Retail, (M)Hotel/Restaurants, (N)Life recreation/Entertainment, and (P)Medical/Welfare have been chosen assuming that discretionary locations are related to those industries such as shops or hospitals. Disaggregation has been performed in the same way as “Working location” in the case of aggregated data. See Appendix A.1 for those ratios mentioned above.

Finally, in order to define “Initial location”, the share from the survey (65.7% for “Home”, 15.3% for “Work”, and 19.0% for “Discretionary”) is applied into the whole population, assigning randomly one of those three potential locations. People are present in those areas at the start of simulation. As summary, the number of residents/workers/visitors given as potential initial locations for each area and the resulting number of people present at the start of simulation is illustrated in Figure 4.5.

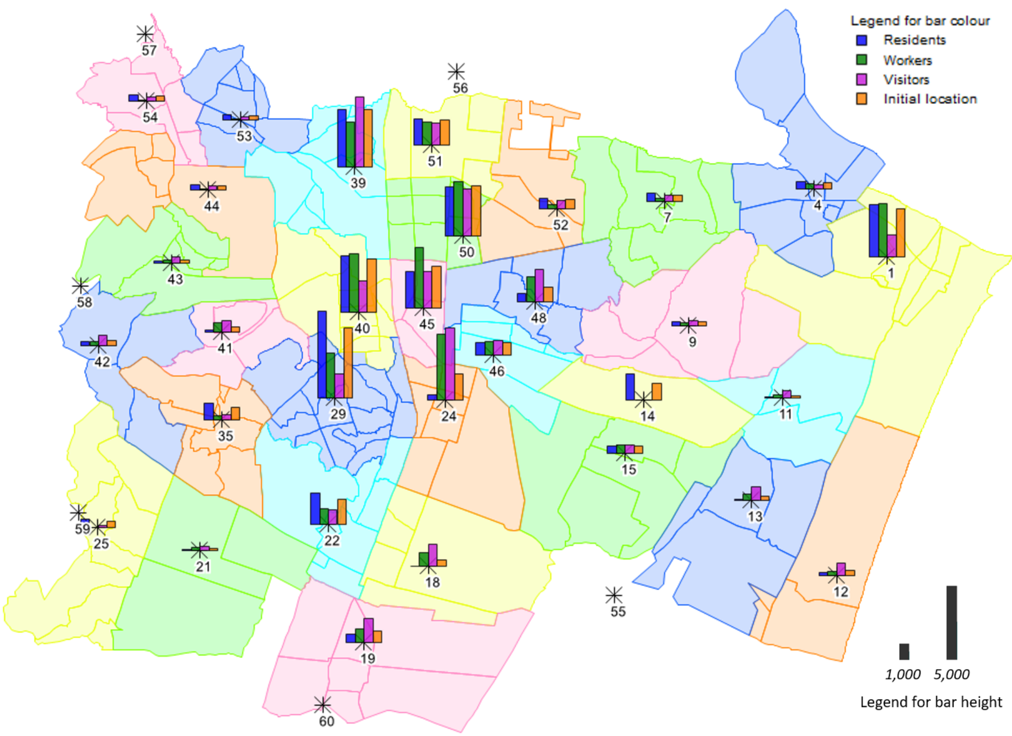

Figure 4.5: Defined area and zonal data. Orange bars are the sum of 65.7% of blue bar, 15.3% of green bars, and 19.0% of pink bars in each area. (OmniTRANS)

4.4. Choice modelling

In this section, the choice model for the synthesized population is explained. An important assumption should be made here with respect to the survey. While interactions between household members are to be modelled using the result of data analysis performed for the survey, the survey does not provide enough about household information of the respondents.

Thus, we do not know whether the result of data analysis can be directly applied into the household level or the individual level. In case the respondents were chosen randomly regardless of their households, the gained frequency of choices need to be translated into the household level. In this study, we assume that the respondents are representatives of households, and thus the choice frequency can be applied directly into choices of household level.

Leave / Stay choice

As shown in the previous chapter, there is a significant association between the leave / stay choice for evacuation and family gathering. People performing family gathering are less likely to evacuate after the gathering. Following the result, the choice frequency for people in the family households (Table 3.4) is applied for the choice for evacuation. It is also proved that the leave / stay choice for family gathering is associated with initial location and age. With regard to the initial location, people tend to gather with their families at the face of earthquake when they are initially at less familiar places. Hence people, for instance, at "Home" are least likely to perform the family gathering compared to when being at other locations such as "Work" and "Discretionary". In respect to age, more significant difference is found between "20-39 yrs" and "above 40 yrs" as shown in Table 3.15. Besides, the significance holds true not only for people having elder person in their households but also for the entire data set. Therefore the choice frequency for "20-39 yrs" and "above 40 yrs" for all the people (Table 4.1) is applied. The choice frequency for the leave / stay choice for family gathering is defined by age and initial location, resulting in Table 4.2. The choice is assigned randomly based on these frequencies to the decision-makers which are to be followed by the other household members.

Table 4.1: Age of travellers for family households

	Family gathering			
	Yes	No	Total	$\tilde{\chi}^2$
20-39 yrs	122	411	533	**5.24***
	22.9%	77.1%	100%	
above 40 yrs	364	1607	1971	
	18.5%	81.5%	100%	
Total	486	2018	2504	
	19.4%	80.6%	100%	

Table 4.2: Leave / Stay choice frequency for family gathering

		Family gathering		
		Yes	No	Total
20-39 yrs	Home	13.3%	86.7%	100%
	Work	30.4%	69.6%	100%
	Discretionary	39.6%	60.4%	100%
above 40 yrs	Home	10.4%	89.6%	100%
	Work	28.5%	71.5%	100%
	Discretionary	39.7%	60.3%	100%

Departure time choice

The departure time for evacuation and family gathering are modelled by assuming distribution types and estimating its parameters based on the survey data. Regarding the departure time for evacuation, a Rayleigh distribution is applied which is given by

$$P(t) = 1 - e^{-t^2/(2*\sigma)}$$

where *P (t)* is the cumulative percentage of total number of people leaving for evacuation at time *t*, σ is a scale parameter reflecting response rates. With respect to the departure time for family gathering, an exponential distribution is applied which is given by

$$P(t) = 1 - e^{-\lambda * t}$$

where *P (t)* is the cumulative percentage of total number of people leaving for family gathering at time *t*, λ is a scale parameter reflecting response rates. Those parameters are estimated by least square method using excel solver and the results are presented in Figure 4.6.

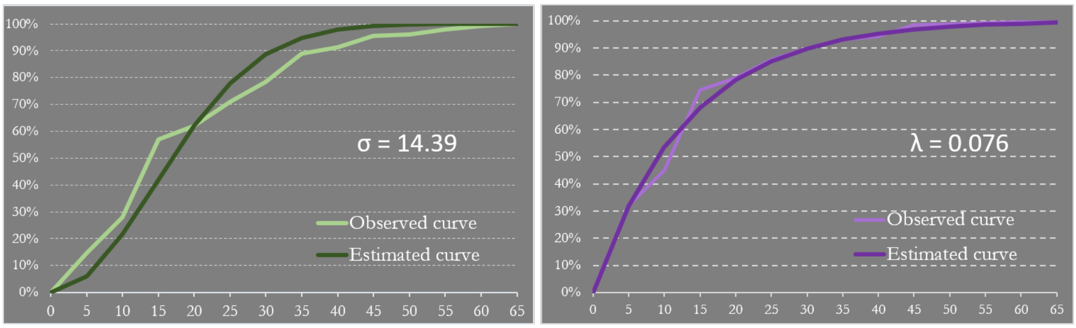

Figure 4.6: Departure time model estimation for evacuation (left) and family gathering (right)

In order to assign the departure time randomly to the population, inverse transform sampling-method is applied to the models that generates random numbers from any probability distribution by using its inverse cumulative distribution $F^{-1}(t)$. Unlike the leave / stay choice, there is no dependency between the household members for this choice.

The evacuation departure time for those who performed family gathering is defined by the arrival time of the household members gathering last, which is to be calculated in the simulation. Therefore, those who arrive earlier than the other household members are to spend some waiting time at the gathering locations.

Destination choice

As discussed in the conclusion of previous chapter, incorporating an association between gender and gathering locations seems difficult due to the large number of other choices which does not show any significant pattern. Therefore, the destination choice for both evacuation and family gathering are modelled using the choice frequency derived from all the alternative in the survey. A modification is made as to the location categories to have further less number of destination location types. As for the evacuation location, "Public facilities" and "Private facilities" are combined as "Building", while "Shrine" is combined into "Higher ground" since shrines used for evacuation are likely to be located on higher ground. Furthermore, due to the lack of information with respect to "Higher ground", "Building" and "Higher ground" are combined. The rest such as "On the road" and "Other" are treated as "Far away" by assuming people to evacuate just towards inland direction. Concerning family gathering location, in addition to the three major gathering locations, "Home", "Someone's home", and "School" accounting for 86% of all the chosen locations, considering more than 5% belonging to either "Public facilities" or "Private facilities", the rest is treated as "Building". The location type is assigned randomly to the whole population based on these choice frequencies (Table 4.3).

The exact location within the chosen location types is to be defined in “Route choice” as the travel time needs to be taken into account.

Table 4.3: Destination choice frequency for gathering and evacuation

Gathering location		*Evacuation location*	
Home	43.1%	Home	9.3%
Someone’s home	16.6%	Someone’s home	7.7%
School	27.1%	School	31.1%
Building	13.2%	Building / Higher ground	40.8%
		Far away	11.1%

Mode choice

The mode choice for family gathering is simulated based on the choice frequency presented in Table 3.3 while the mode choice for evacuation is modelled differently between those who performed the family gathering and those who did not. As presented in the previous chapter, those who performed the family gathering are more likely to evacuate by car than those who did not. However, modelling car passenger is challenging task in case that household members are scattered in different locations and that car ownership can not be identified in the survey. Therefore, it has been decided that “Driving” and “Car passenger” are combined for the choice frequency and that is applied in the simulation assuming everybody has an access to cars. The frequency for those who performed the family gathering is 64.3% for “Driving/Car passenger” and 35.7% for “Walking” whereas 57.5% for “Driving/Car passenger” and 42.5% for “Walking” for those who did not. After applying these frequencies that generate initial mode choice, “Car passenger” mode can be generated for cases where people choosing “Walking” have household members choosing “Driving/Car passenger” in the same area. In this case, a mode change is performed from “Walking” to “Car passenger”. This can happen either when household members gather or by chance at the initial location. Conversely, a mode change from “Driving/Car passenger” to “Walking” is performed in cases of people choosing “Driving/Car passenger” for evacuation while choosing “Walking” for family gathering on the condition there is no household members choosing “Driving/Car passenger” to help. This is because it is not realistic to assume there are cars available in gathering locations such as “School” and “Building”. Lastly, family members in the same area take a single car even if more than one member choose “Driving”. In this case, a mode change from “Driving/Car passenger” to “Car passenger” is made.

Travellers in individual households

Due to the small size sample size, family gathering behaviour for people in individual households has not been statistically proved although the data indicates there were such people gathering with families living separately in different areas. For this reason, we assume that those people does not perform the family gathering but some evacuate directly from the initial locations. For their evacuation choice model, it is defined by the choice frequency from the survey. The departure time for evacuation is assumed to follow the same model as the traveller in family households (see Figure 4.6).

Table 4.4: Choice frequency for travellers in individual households

Evacuation		*Destination*		*Mode*	
Yes	42.5%	Home	10.7%	Driving/Car pass.	53.6%
No	57.5%	Someone's home	3.6%	Walking	46.4%
		School	29.7%		
		Building/Higher ground	41.7%		
		Far away	14.3%		

Route choice

In order to define the route choice, route choice sets firstly need to be generated from all the links, including all the origins, to all the destinations. Following the method by van der Gun et al. [66], Monte Carlo approach to compute multiple next-best routes and Dijkstra [11] algorithm to extract the shortest paths are applied for the route set generation. For Monte Calro simulation [13] where link travel time τ from normal distribution with mean equal to the free flow travel time τ_0 :

$$\tau = \max\{\tau_0 + \epsilon\sqrt{\theta\tau_0}, 0\} \quad with \quad \epsilon \sim N(0, 1)$$

200 iterations are performed with the dispersion coefficient linearly increasing from zero to 0.002(h) and Dijkstra algorithm is applied in each iteration. This route choice set generation is performed only once.

Given the location type defined in "Destination choice", the exact location for gathering and evacuation are to be chosen from the sets of alternatives except "Home" and "Someone's home" already defined in the population synthesis. The set of alternatives for "School", "Building", and "Far away" is shown in Figure 4.7. As for gathering location, instead of letting decision-makers to make the choice followed by other household members, it has been decided that the nearest "School" and "Building" from their residential locations regardless of their initial locations is chosen. This assumption can be justified considering people to choose rather familiar places or schools their children would go. The nearest location from their residential locations is defined by the travel time calculated by the free flow speed being applied into the route choice sets given previously. Speaking of the exact location for evacuation performed individually or with household members where the nearest location from their current locations is considered, the travel time is calculated taking congestion into account where the road profile in Table 4.5 is considered. Intra-zonal trips, where origin and destination are the same, are allowed and trips are made from one connector to the other by taking surrounding routes. Besides, en-route route choice is also considered and people may change their initial route on the way.

As a summary of this section, an overview for the choice modelling is depicted in Figure 4.8.

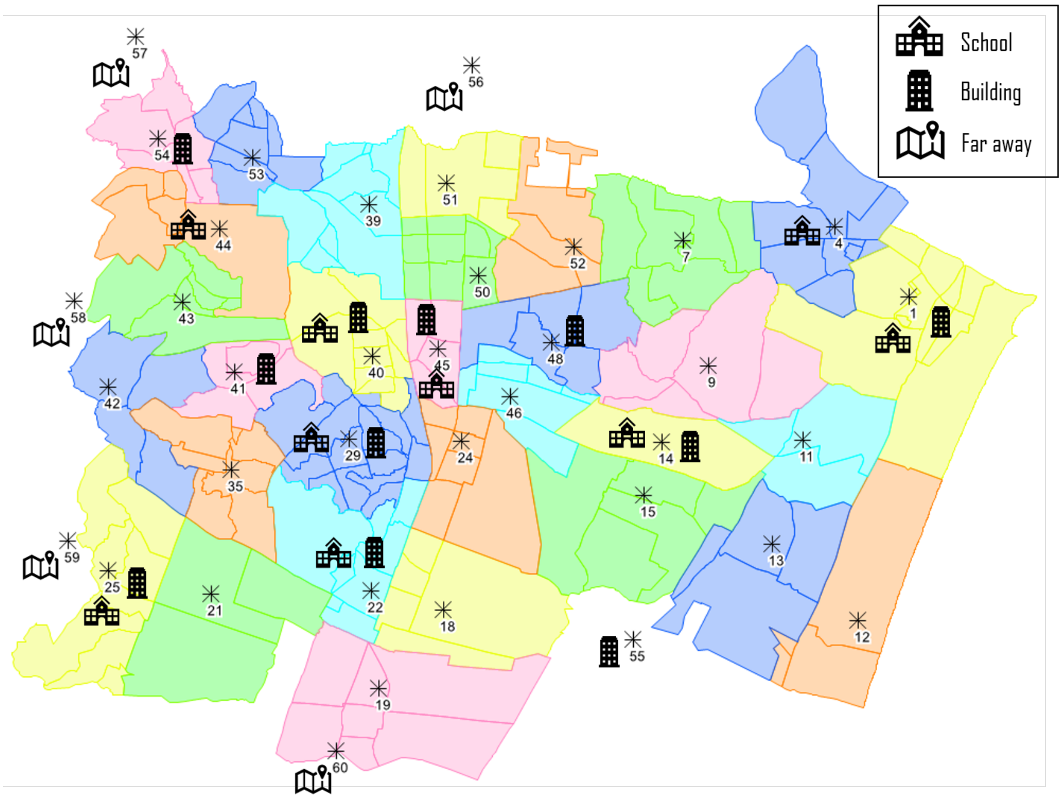

Figure 4.7: Areas with some location types for destination choice (OmniTRANS)

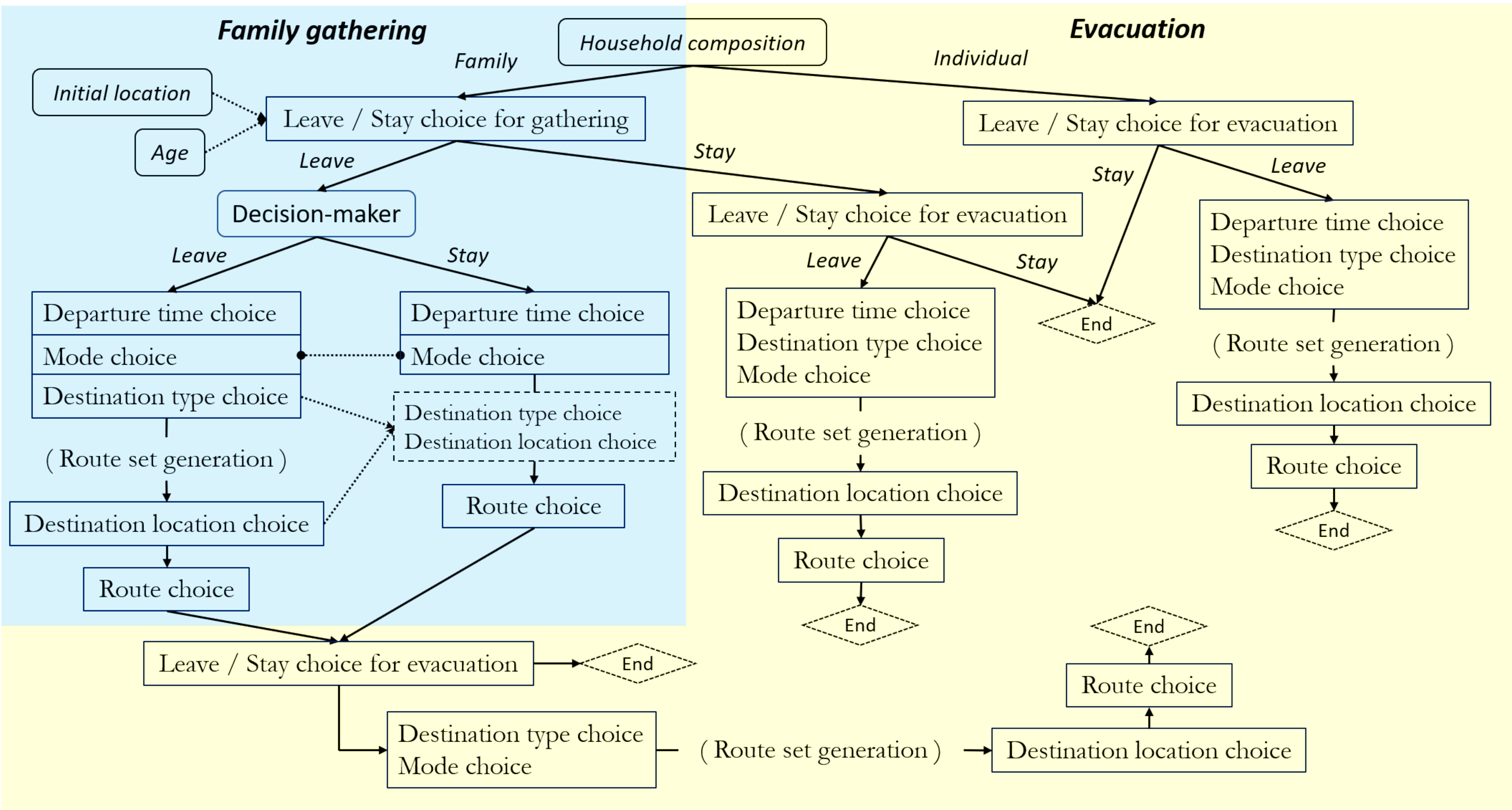

Figure 4.8: Flow chart overview for the choice modelling

4.5. Simulation

A simulation is carried out for the synthetic population and the choice model using the simplified version of the model by van der Gun et al. [66], and visualized in OmniTrans 8.0.20. For the transport network explained in the previous section, different capacity and different speed are applied for each road type. Besides, all the defined areas are connected to those transport network by multiple connectors where vehicles and pedestrians pass to depart from and arrive at each area. All the pedestrian streets are given the same speed and the same capacity such that congestion does not occur. All the road profile is presented in Table 4.5. Besides, it should be noted that no traffic lights are modelled in this simulation.

Table 4.5: Speed and capacity of the transport network

	Max.speed (km/h)	Capacity (veh/h/lane)	Free flow speed (km/h)	Saturation flow (veh/h/lane)	Jam density (veh/km/lane)
Arterial road (veh.)	60	1800	60	1800	150
Local road (veh.)	40	1600	40	1600	150
Shortcut (veh.)	20	1200	20	1200	150
Connectors (veh)	20	900	20	900	150
Pedestrian street	5	9999	5	9999	-

Result

The summary of indicators for trip type and mode is presented in Table 4.6. Trips only for evacuation and trips for evacuation after gathering are separated because these have different characteristics.

Modal share

First of all, the modal share is discussed since this is the only choice, apart from the route choice defined only during the simulation, where the result is not necessarily consistent with the choice frequencies applied due to the mode change made by the interaction between the household members. As for family gathering trips, because of the higher percentage of people initially at home (65.7%) and the concentration of business in the downtown, there seems to be many cases where household members are initially in the same location, which results in 22.9% of “Car passenger” for gathering trips. It appears that more people switch their mode from “Walking” to “Car passenger” given the applied frequency of “Walking” (24.9%) in the choice model. Contrarily, “Car passenger” for evacuation only trips are quite low (3.5%). This can be attributed to 23.6% of 1 adult household that does not have a choice of “Car passenger”, otherwise the share should be similar to that of family gathering trips. Regarding evacuation trips after gathering, the share of “Car passenger” is obviously higher than the other trip types since all the household members are together. Considering the applied frequency of 64.3% of “Driving/Car passenger”, this seems to be achieved by household members choosing “Driving/Car passenger” but using a single car for evacuation trips rather than people choosing “Walking” and joining a car driven by their household members.

Congestion

Because of “Walking” not involving congestion, this section discusses the vehicle congestion observed in the simulation.

Table 4.6: Summary of indicators

		Gathering	Evacuation only	Evacuation after gathering	Total
Modal share	Driving	60.8%	58.9%	24.0%	57.2%
	Car passenger	22.9%	3.5%	35.5%	11.1%
	Walking	16.4%	37.6%	40.5%	31.7%
Driving	Trips completed	3627	6104	270	10001
	Trips uncompleted	783	3511	119	4413
	Ave. Travel Distance (km)	3.3	2.7	2.3	2.9
	Ave. Travel Time (min)	48.1	62.1	30.8	56.2
	Ave. Travel Time delay	883%	1283%	722%	1123%
	Ave. Travel Speed (km/h)	10.9	7.5	16.4	9.0
Walking	Trips completed	1189	6812	646	8647
	Ave. Travel Distance (km)	3.1	2.0	1.8	2.1
	Ave. Travel Time (min)	37.6	24.2	20.7	25.9
	Ave. Travel Speed (km/h)	4.9	4.8	4.8	4.8

As the summary of indicators shows, overall nearly one third of the trips are not to be completed even in three hours because of some congestion. This is proved in the indicators calculated in average only for the completed trips. Whereas the average travel distance (2.9 km) is within expectations given the size of the city, the average travel time (56.2 min) is considerably high, which explains the average travel speed being quite low, 9.0 (km/h). This causes an average delay of more than ten times the free flow travel time (1123%). Figure 4.9 shows the most congested period of the network which is 15 minutes after the earthquake. Around this period of time, more vehicle are leaving their initial locations and some are arriving at their destination. This congestion is, however, released 60 minutes after the earthquake in the large parts of the network as shown in Figure 4.10. Severe congestion remains to be seen around the arterial road and only around the centroid No 1, Yuriage.

Looking closely at it per trip type, the share of uncompleted trips are clearly higher for the evacuation only trips than that of the gathering trips, being backed up by the other indicators. Although the average travel distance for the evacuation only trips is smaller than that of the gathering trips, the average travel time for the evacuation only trips is larger than that of the gathering trips due to the slower speed. The longer travel distance for the gathering trips is considered to be attributed to the destination type choice. In addition to “Home” and “Someone’s home” accounting for an half the destination location type where the exact location are fixed, the exact location for “School” and “Building” are chosen also depending on “Home” location. The destination choice for the evacuation trips, on the other hand, takes the current location into account, choosing rather nearby locations. It should be questioned whether the route choice for the evacuation only trips considering congestion leads to choosing locations further away from the current location. This seems to be avoided by the fact that evacuation locations such as “School” and “Building” are situated different parts of the city, and those evacuation locations can be accessed from the congested downtown area in the short distance. Those centroids surrounding the congested areas attract more evacuation only trips than gathering trips. For example, centroids number 14/22/41/48 account for 27.8% of the total trip attraction for the evacuation only trips while 17.0% for the gathering trips. More gathering trips are instead directed to the congested areas where they have home. For example, centroid number 29/40/45 are responsible for 45.3% of the total trip attraction for the gathering trips whereas 31.7% for the evacuation only trips, which can be observed in Figure 4.12 (See Appendix A.3/4/5/6 for OD matrix). For the reason of the longer travel

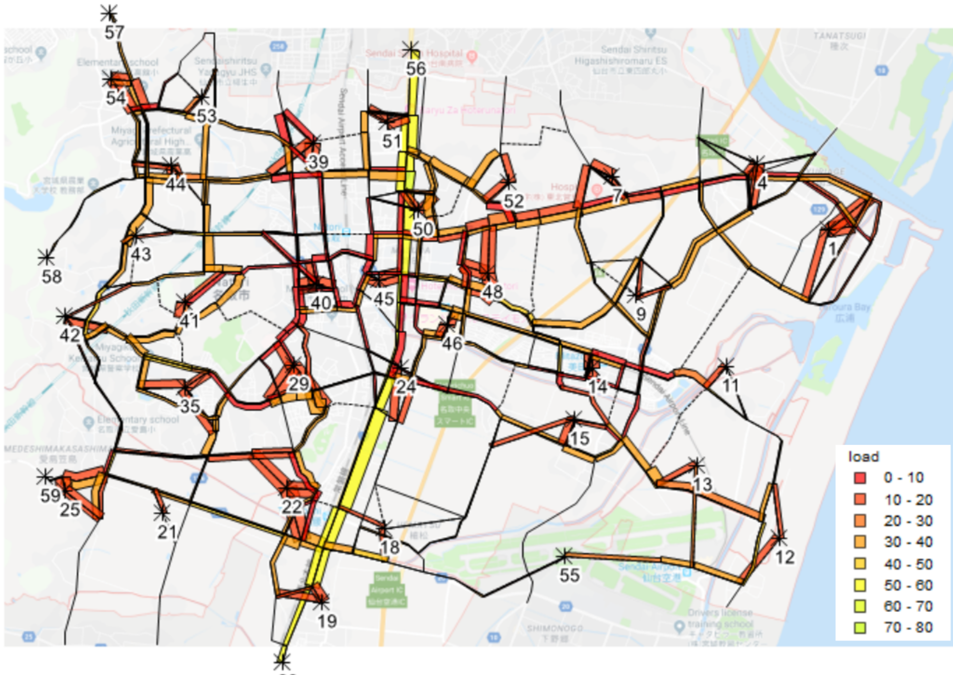

Figure 4.9: Average traffic flow and speed in 15 min. Bar widths are proportional to traffic flow, colours indicate its speed. Congestion can be observed in many areas. (OmniTRANS)

time and the slower travel speed for the evacuation only trips, an attention needs to be paid to “Departure time choice”. As presented in “Choice modelling”, the distribution of departure time choice for the gathering trips and the evacuation only trips take different forms; an exponential distribution for the gathering trips and a rayleigh distribution for the evacuation only trips. Because of this difference, a larger percentage of people departs by car in the first ten minutes from their initial locations for the gathering trips (62.7%) than for the evacuation only trips (20.7%). During this ten minutes, as observed in Figure 4.11, the average speed is around 30 (km/h) but it goes down to around 6 (km/h) afterwards due to the increasing congestion, which seems to contribute to the difference in the travel speed.

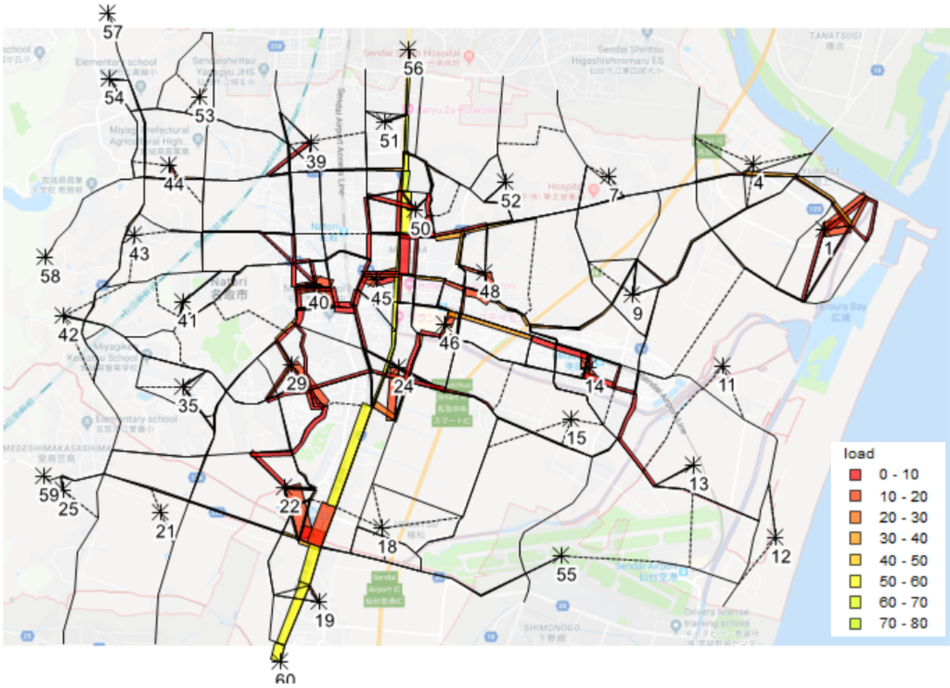

Figure 4.10: Average traffic flow and speed in 60 min. Bar widths are proportional to traffic flow, colours indicate its speed. Congestion can be observed only around certain areas. (OmniTRANS)

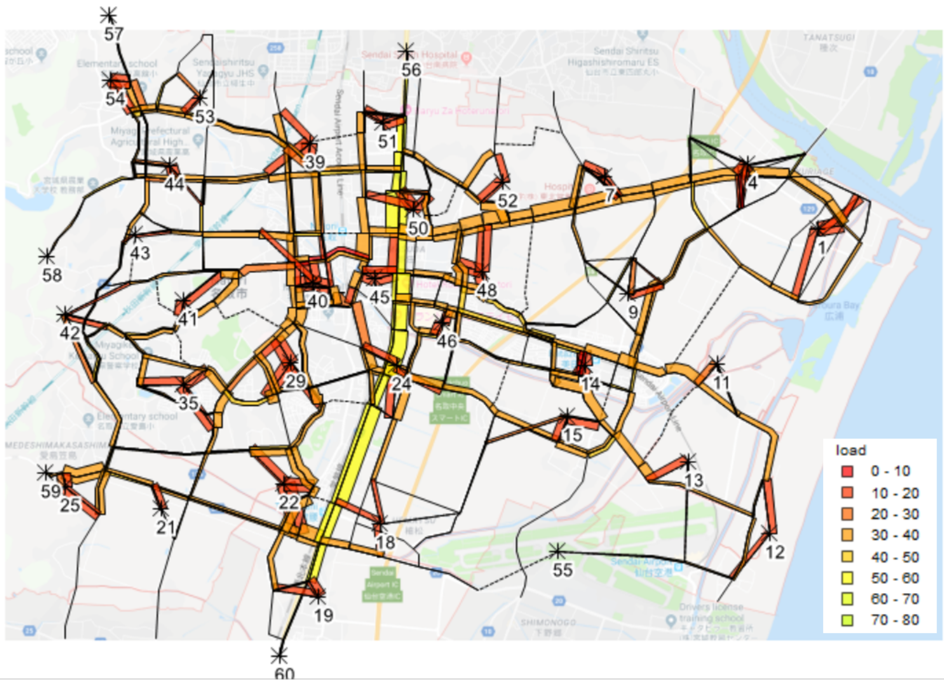

Figure 4.11: Average traffic flow and speed in 5 min. Bar widths are proportional to traffic flow, colours indicate its speed. More traffic with maximum speed can be observed over the network. (OmniTRANS)

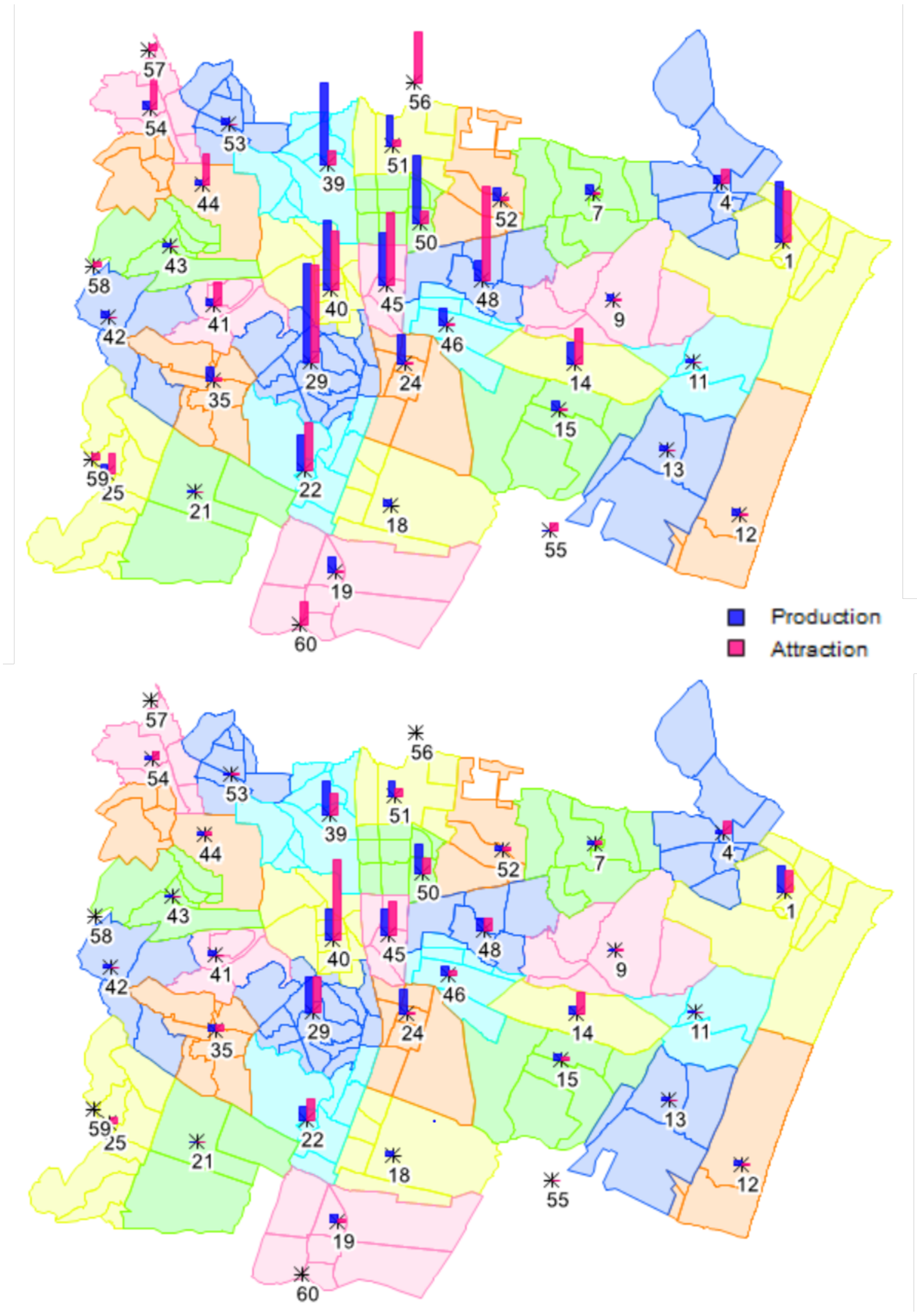

Figure 4.12: Trip generation for the evacuation only trips (above) and the gathering trips (below). Some trips are directed to the areas surrounding the downtown area for the evacuation only trips while more trips are concentrated around the downtown area for the gathering trips. (OmniTRANS)

Pedestrians

As for the pedestrian traffic, since it does not take congestion into account, the average travel distance and the average travel time are proportional unlike the vehicle traffic. All the trips are completed within the time frame. Although the destination type choice is modelled in the same way as “Driving”, the average travel distance is slightly shorter for “Walking” because of some pedestrian only roads. It should be noted that, if the highway was considered as an evacuation location for pedestrians, it would reduce the travel time since it runs through several areas with neither “School” nor “Building” such as centroid number 7/9/18/19/24/48, providing alternative locations.

4.6. Validation

In this section, the validity of the result is discussed by comparing the result with the observation in the survey only for Natori presented in Table 4.7. It should be noted regarding the survey data that it is self reported data based on the respondent’s memories about the event that occurred more than a half year earlier. The memories about mode they used or destination they evacuated to would not be too inaccurate, but the time they departed or arrived would be considered not as accurate as the others. Besides, some outliers have been excluded to avoid the result to be biased. Trips with distance longer than 9 km (n=5) and trips with travel time longer than 3 hours (n=17) are assumed trips reached outside the city given the size of the city, and thus removed. Also, the travel distance is an euclidean distance calculated based on the two points, origin and destination, reported for every trip, which is used with the mentioned travel time to calculate the travel speed. In order for travel distance for the simulation to be more comparable with this travel distance from the survey, the euclidean distance between two centroids are used rather than the travel distance in the simulation, which results in 2.3 (km) for the gathering trips and 1.9 (km) for the evacuation trips in average for “Driving”, and 2.4 (km) and 1.6 (km) respectively for “Walking”.

Table 4.7: Trip indicators in Natori based on the survey (N=360)

		Gathering	Evacuation	Total
Modal share	Driving	52.7%	35.1%	40.8%
	Car passenger	14.3%	22.5%	19.8%
	Walking	33.0%	42.4%	39.4%
Driving	Ave. Travel Distance (km)	2.1	1.9	2.0
	Ave. Travel Time (min)	15.2	20.9	18.6
	Ave. Travel Speed (km/h)	9.2	8.3	8.7
Walking	Ave. Travel Distance (km)	0.49	0.50	0.50
	Ave. Travel Time (min)	20.8	11.7	14.3
	Ave. Travel Speed (km/h)	3.1	2.6	2.7

With respect to the mode choice, there are more cars simulated than what the survey indicates, taking the share almost equally from “Walking” and “Car passenger”, because of “Driving” and “Car passenger” being combined in the choice model and the interaction of household members. This would certainly overestimate the number of trips by car in the simulation, being one of the reasons of the severe congestion previously discussed.

The average travel distance calculated by euclidean distance in the survey and in the simulation are almost the same for “Driving” but considerably different for “Walking”. This would suggest that those centroids are too coarse for pedestrians while that is reasonable for cars. In addition, those locations for the destination choice (Appendix A.2) seems insufficient for pedestrians given that short average travel distance for "Walking". More higher buildings may need to be identified to make this part more valid.

The travel time in the simulation is considerably higher than those in the survey despite the fact that the two travel distance for "Driving" are quite similar. Here whether the congestion simulated is valid or not comes in. Looking at the average speed, there seems to be no major difference in the speed between in the survey and in the simulation and both indicate that there are speed reduction over time (see Figure 4.13), showing some congestion being built up over time. This might prove a certain level of validity of the model.

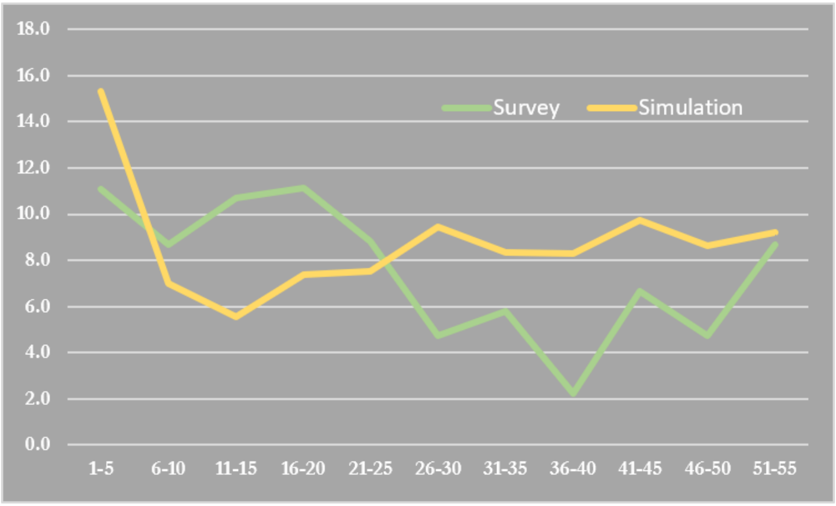

Figure 4.13: Average vehicle speed over time for the survey and the simulation (x axis for time in minutes, y axis for speed in km/h)

Figure 4.14 shows the evacuation rate in time for the survey and the simulation for "Driving" and "Walking". For the survey, the latest arrival time of evacuation trips is assumed to be 100%, which is 20:00 on the day. Since the simulation is performed in three hours, x axis is set to be the same time frame. According to the survey, almost all the pedestrians have completed the evacuation after an hour while nearly 80 % of the drivers also have dome the same. This is consistent with the simulation for "Walking" showing the similar curve. However, as presented in the previous section, nearly one third of the evacuation trips for "Driving" for the simulation is not completed within the time frame, showing an indisputable discrepancy from what the survey indicates. "Driving" for the survey seems to indicate that there was no major congestion during the evacuation given the similar evacuation rate as "Walking", which contradicts what the speed reduction suggests. The validity of the model should be discussed in this regard.

Conclusion and discussion

In this chapter, tsunami evacuation is modelled and simulated taking the family gathering behaviour studied in the previous chapter into consideration for the purpose of presenting the methodology. The choice model, which is the main part of the methodology, is discussed after the descriptions of "Case study location" and "Population synthesis".

In order to model the family gathering, "Population synthesis" needed to be constructed such that household members can be identifiable. This has been done by creating first

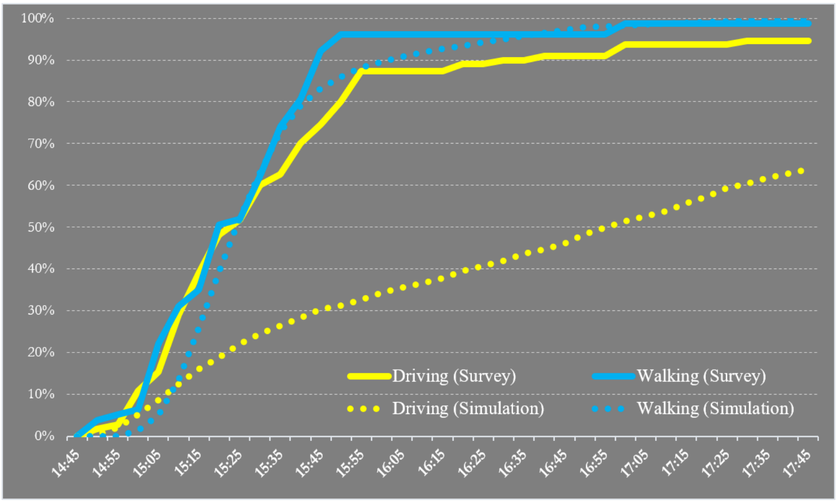

Figure 4.14: Evacuation completion rate per mode for the survey and the simulation

"Household attributes" and then assign the household id to individuals. Also, in order to simplify a joint decision-making among household members, a decision-maker is assigned to one of the household members as "Individual attributes". It has been assumed that the choices made by the decision-makers are followed by the other household members.

For the most of the choice model, the choice frequency identified in the survey by MLIT has been applied. For this purpose, the respondents for the survey are assumed to be representatives of households, and thus the choice frequency can be applied directly into choices on household level. For "Leave / Stay choice", the age and the initial location are incorporated in the choice frequency as the survey suggests that these have associations with the choice. As for "Departure time choice", following the finding that the departure time for the evacuation and the family gathering follows different distributions, the parameters are estimated based on the observation, and those distributions are directly applied in the choice model. With respect to "Destination choice" where destination location types have been identified, due to the large number of alternatives found in the survey, the choice frequency are applied after combining some alternatives. "Mode choice" for the evacuation incorporates the association that people performing family gathering are more likely to use a car, resulting in different choice frequencies applied into the choice model. "Mode choice" for family gathering applies the choice frequency without any association. In addition to these, some mode changes are modelled for the interaction between the household members, making some to switch from "Driving" or "Walking" to "Car passenger". Regarding "Route choice" where no behavioral analysis have been carried out in the previous chapter, the methodology by van der Gun et al. [66] has been applied which allows en-route choice out of the route sets defined by Monte Carlo simulation and Dijkstra algorithm. The exact location for "Destination choice" is defined, given the destination location types chosen previously, based on the travel time for each route.

The simulation has been carried out using the model by van der Gun et al. [66] which provides the result where the severe congestion is to occur mainly around the downtown. Because of this, there are supposed to be a large number of vehicles not reaching their destination even in three hours after the event. The result has been compared to the survey to discuss the validity. Similar to the result of the simulation, the survey shows a speed reduction over time, suggesting a validity of the model in terms of congestion. However, several deviations are confirmed for other indicators showing a certain level of imperfect validity, assuming the survey represents what happened in reality. More part of the model seems to overestimate the traffic while some parts appears to underestimate the traffic. The reason for the possible imperfect validity can be attributed to several factors.

First of all, any part of the model does not take geographical variables into account. The distance to the coastal line, for example, is considered one of the important variable in modelling evacuation since there is higher risk of inundation at locations closer to the coastal line, and thus it can be assumed people being close to the coastal line are more likely to perform evacuation. It has been modelled, however, that people in any part of the city perform either family gathering or evacuation at the same probabilities. This would result in more people performing those trips in this case study since the majority of people live and work in the downtown area, which is about 5 km away from the coastal line, and they would not perform evacuation trips as much as those living close to the coastal line. “Mode choice”, defined regardless of the distance travelled, should also consider geographical variables because it is obvious that people travelling a longer distance are more likely to drive than to walk, and versa versa. Because of this, the travel distance and the travel time can be considered different from the reality, overestimating for “Walking” and underestimating for “Driving”.

There also can be a discussion about the synthetic population developed out of some census data. Because of the lack of household-related information in the survey data, several assumptions had to be made. The household composition and age of the household members have been assumed. Relative/Friend’s home expressed as “Someone’s home”, “Working location”, and “Discretionary location” for destination location have been randomly assigned over the entire city while in reality those locations are assumed to have correlations with “Residential location”. This could overestimate the travel distance, causing more congestion than it should be.

5

CONCLUSIONS AND RECOMMENDATIONS

Over the course of this project, several research have been carried out in order to answer the research questions set in the beginning. In this final chapter, conclusions are drawn for each research question. After discussing also about the fulfillment of the research objective, some recommendations are provided for the future research.

5.1. Conclusions

> *RQ1. What were the evacuation choices by people who performed the family gathering significantly different to those who did not during the evacuation?*

It has been found that there are several choices by people who performed the family gathering significantly different to those who did not. ”Leave/Stay choice” for evacuation significantly differs depending on whether they performed the family gathering or not. People who performed the family gathering were less likely to evacuate. ”Departure time choice” for people who performed the family gathering forms the distribution significantly different from those who just evacuated, indicating the former tend to leave their initial locations earlier than the latter who seemed to need more time to decide. Behaviour significantly different between those two groups is also found in ”Mode choice” for evacuation where people who performed the family gathering were more likely to evacuate by car than those who directly evacuated. These findings appear to indicate that taking family gathering behaviour into evacuation modelling should not be undervalued.

> *RQ2. What were statistically significant parameters defining those people who performed the family gathering during the evacuation?*

Four parameters, considered as such significant parameters by some previous studies, have been investigated to check the association and it has been suggested that ”Initial location”, ”Gender”, and ”Age” can be variables defining those who performed the family gathering. As for ”Initial location” having an association with ”Leave/Stay choice”, people initially at home were less likely to perform the family gathering than those at work in the face of the earthquake, and people initially outside or at shops were more likely to perform the family gathering than those at work. Regarding ”Gender” being associated with ”Destination choice”, women were more likely to go to ”School” than men, and men were more likely to choose ”Home” than women for the family gathering. With respect to ”Age”, an association has been found in ”Leave/Stay choice”, suggesting that older people are less likely to perform the family gathering compared to younger people. ”Employability” considered to have an association with ”Destination choice” did not show any significance as a parameter in this study.

RQ3. How those family gathering behaviour can be simulated in the activity-based transportation model for emergencies?

Using the choice frequency of alternatives reported in the survey, three choices, ”Leave/Stay choice”, ”Destination choice”, and ”Mode choice” have been modelled taking the variables identified as significant parameters into account. Two important assumptions have been made for this. One is that the respondents for the survey are representatives of households, and thus the choice frequency can be applied directly into choices on household level. The other is that there is a decision-maker in each household and their decisions are followed by the other household members. Different choice frequencies have been applied for ”Leave/Stay choice” depending on ”Initial location” and ”Age” while the choice frequencies for ”Mode choice” are modelled to be differ between those who perform family gathering and those who do not. Also, the interaction of household members being in the same area is modelled making people to change a mode either from ”Walking” and ”Driving” to ”Car passenger”. As for ”Destination choice”, the choice frequency developed out of the survey have been applied, defining the destination location type used for ”Route choice”. With respect to ”Departure time choice”, two different distributions have been assumed to develop the model; exponential distribution for family gathering and rayleigh distribution for evacuation. The parameters have been estimated based on the survey data and those distributions have been applied for the choice model. ”Route choice” is defined, in parallel with the exact location choice, by the shortest path chosen out of the defined route sets. Congestion is taken into account for evacuation destination, whereas family gathering destination is defined by the nearest location from ”Home” location.

RQ4. How those insights about the evacuation can be generalized for the future tsunami in different places?

Concerning the first research question, since those findings are new except ”Mode choice”, a generalization of it should be carefully considered. However, the conclusion for this question is only about the association between the two choices or the difference between the two choices instead of to what extent they are associated. In this respect, applying these findings into tsunami evacuation in different places should not be too peculiar. In regard to the second research question, those findings have been derived from the hypotheses based on the previous studies and those studies were carried out in different places. In this regard, it is more likely to be possible to generalize it. However, as shown in the formulation of those hypotheses, various contexts such as situational, cultural, and geographical should be carefully considered when applying these findings. As for the third research question, the methodology should be generalizable as it is independent from the behavioral findings. There might need to be adjustments or improvements depending on what data is available for population synthesis or choice frequencies. However, it is straightforward and less computationally intensive that can be done in Microsoft Excel.

> *Gaining insights into evacuation behaviour considering family gathering activities, and presenting a methodology of how those behaviours can be modelled in the simulation.*

The objective of this study above has been fulfilled by answering those research questions. With regard to the behavioural insight, some choice behaviour related to the family gathering and some explanatory parameters for those behaviours have been revealed. These findings are theories that can be referred for the future studies. As for the methodological part, the simple and straightforward way to model the family gathering behaviour during the evacuation has been suggested. Generalization of those insight can be possible although some attentions need to be paid to the context. For the future research on tsunami evacuation, therefore, this project can be a scientific contribution in terms of evacuation behaviour and evacuation modelling methodology for the family gathering during evacuation. Also, as explained in ”Introduction”, taking this particular behaviour into account for evacuation modelling leads to better prediction of evacuation trips, which in turn helps develop enhanced evacuation planning.

5.2. Recommendations

As discussed in the previous chapter, not taking geographical variables into account do not seem convincing to capture evacuation behaviour. The distance from the coastal line should be considered for the stay / leave choice, and the distance travelled should be taken into account for the destination choice and the mode choice. Without taking it into account, it can model those choices inaccurately, causing either underestimation or overestimation for simulating the model.

In this study, the simulation is a way to check the applicability and the validity of the model. Thus, scenario analysis has not been performed to figure out what could be done to deal with the family gathering activities. For example, the impact made by the family gathering on the transport network can be investigated better by changing the choice frequency or how it could look like under the current transportation network enhanced after the event. Those things can be useful for the authorities to develop evacuation planning.

The tsunami on the day of the event also has not been modelled. A series of video interviews to the evacuees by Japan’s national public broadcasting organization indicates that some people changed activities after the visual confirmation of the tsunami waves. The survey provides the information about whether the respondents saw the tsunami waves which can be one of the parameters defining the family gathering. Besides, simulating the tsunami in parallel with the evacuation enables to identify the casualty by the tsunami, which can be used to evaluate the impact of the family gathering on the casualty or to validate the model.

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A

Apendix

Table A.1: Number of households per age and household composition (left), the ratio to allocate “Working location” and “Discretionary location” (right)

	1 adult		2 adults		4 adults			Employee population	Business register
Area	20-39	Over 40	20-39	Over 40	20-39	Over 40	Total		
1	73	226	238	738	107	332	1714	3.95%	9.71%
4	13	35	36	96	15	39	234	0.61%	0.86%
7	6	20	29	101	19	66	241	1.18%	0.55%
9	3	11	9	35	11	43	112	0.95%	0.55%
11	2	6	3	7	4	13	35	1.42%	0.63%
12	2	10	8	29	11	41	101	2.46%	0.94%
13	1	2	3	8	4	15	33	2.57%	1.10%
14	174	63	524	190	61	22	1034	0.00%	0.00%
15	3	10	22	68	22	65	190	1.47%	1.33%
18	0	0	0	0	0	0	0	3.97%	2.43%
19	17	38	53	118	19	43	288	4.33%	2.58%
21	1	3	1	4	4	13	26	0.62%	0.47%
22	88	153	240	414	73	126	1094	2.62%	2.90%
24	21	38	31	54	9	17	170	12.95%	11.59%
25	5	18	20	75	23	85	226	0.38%	0.08%
29	169	461	562	1530	120	327	3169	4.45%	8.07%
35	40	47	171	206	45	53	562	0.74%	0.70%
39	205	317	553	854	104	162	2195	12.62%	8.38%
40	208	403	449	868	93	180	2201	5.80%	10.49%
41	6	6	16	13	7	7	55	2.22%	1.64%
42	3	11	12	41	10	34	111	1.89%	0.78%
43	1	2	3	8	7	17	38	1.16%	0.47%
44	2	9	16	57	13	46	143	0.84%	0.31%
45	203	350	287	492	65	113	1510	6.73%	10.73%
46	76	54	204	144	23	16	517	2.74%	2.43%
48	18	47	42	111	19	49	286	5.71%	4.70%
50	247	415	421	704	83	139	2009	8.71%	9.87%
51	97	166	212	366	55	94	990	3.97%	4.31%
52	15	43	38	107	26	73	302	1.47%	0.78%
53	3	12	16	55	14	46	146	0.76%	0.31%
54	5	16	20	66	17	55	179	0.71%	0.31%
Total	1707	2992	4239	7559	1083	2331	19911	100%	100%

Table A.2: “School”& “Building” for destination location choice

Area	School	Building	
		Public facilities	Private facilities
1	Yuriage Junior High School	Yuriage Community Center	
4	Yuriage Elementary School		
14	Shimomasuda Elementary School	Shimomasuda Community Center / Rehabilitation Support Center	Super Viva Home
22	Tatekoshi Elementary School	Tatekoshi Community Center	
25	Medeshima Elementary School	Medeshima Community Center	
29	Fujigaoka Elementary School	Natorigaoka Community Center / Miyagi Psychiatric Center	
35			Musashi
39			York Benimaru / Homac / Trial
40	Masudanishi Elementary School / Daiichi Junior High School	Masudanishi Community Center	
41		Miyagi Cancer Center	
44	Daini Junior High School		
45	Masuda Elementary School	Masuda Community Center	
46			Aeon Mall
48	Masuda Junior High School	Natori City Cultural Center / Natori City Hall / Natori Gymnastics	
50			
51			Daily Port Fresh Museum
54	Takadate Elementary School	Takedate Community Center	
55		Sendai International Airport	

Table A.3: OD matrix for the gathering trips by “Driving” (The number of trips between origin (horizontal) and destination (vertical))

	1	**4**	**7**	**9**	**11**	**12**	**13**	**14**	**15**	**19**	**21**	**22**	**24**	**25**	**29**	**35**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**48**	**50**	**51**	**52**	**53**	**54**	**55**	**Total**
1	108	45	3	1				11		1	1	10	1	3	15	2	7	24				2	11	2	1	6	5	1		1		261
4	7	21						1							5		3	3					3		2	1	2					48
7		4	16			1								1	1	1	4	7					2		4	3						44
9	1			6				9					1				2	4								1						24
11		4		1	3			4				1			3	2	1	4	1				5			2		1				32
12	3	1				3		10				3		1	6	1	2	7					5		1	1	1				5	50
13	3	1	1				1	3				4		1	2	1	3	5					6		3	4	2	1		1		42
14	1	1						91	1	1		1				1	2	4									1					104
15	4		2					14	14			2		2	4	1	1	10					7	1	3	3			1			69
18	7	1						4				10	2	1	7	3	1	12		1			11		3	2	2	1		1	1	70
19	2	2	1	1				4		13		20	1		11		5	17				1	14	1	1	3	3	1		2		103
21											2	1		3	3	1	4	2					1			1						18
22	11	3					1	9	1		1	98			9	3	3	18		1			3	1	4	5			1	3		175
24	16	11	3	3		1		20	2	2	1	20	6	6	28	3	19	80		1		1	45	2	8	21	3	3	1	8	1	315
25	1											1		27			1	2								1				1		34
29	6	2	1	1	1	2		5	1	4		10	1	2	130	2	12	119		1		5	6	4	3	5	7	1		5		336
35	1	1	1					2	1			4			25	28	2	11					3		1	3	1		1			85
39	6	9	4	1	2			4		3		4	1	2	16	2	77	91	1			3	14	1	5	7	5		1	1	1	261
40	15	5						11	1	1		12		4	20	5	15	171				6	18	2	4	8	4	2		4		308
41	3	2				1		3	2			2		1	7	2	4	18	3			1	1	2	5	6				2		65
42			1									2		4	4	2	1	7	2	4		1	3			1	1			1		34
43	2	1											1	2	3		4	5			1	3	1			1		1				25
44															5	1	3	4				13	1							6		33
45	10	5		2				12		2		9	3	2	12	3	8	79			2	2	57	6	3	7		3	1	4		232
46	2	5	1		1			5		2		5			10	1	5	17		1			8	32	27	3				2	1	128
48	6	4	1					12	2	1		5		1	16	1	8	27				1	21	3	29	5	8			6		157
50	13	4	3		1			13	1	3		8	1	3	19	5	21	34	1			2	72	3	9	57	5		1	4		283
51	3	1			1			7		2		5		1	13		6	32		1		1	52		7	3	25	1			1	162
52	1			1				2	1			2			3			6					2		16	2	2	11		1		50
53		1								1		1			1	1	2						2		1	1	2		3	11		27
54	1	1										2				1	2	3					2			1	1			27		41
Total	233	135	38	17	9	8	2	256	27	36	5	242	18	67	378	73	228	823	8	10	3	42	376	60	140	164	80	27	10	91	10	3616

Table A.4: OD matrix for the gathering trips by “Walking” (The number of trips between origin (horizontal) and destination (vertical))

	1	4	7	9	11	12	13	14	15	19	21	22	24	25	29	35	39	40	43	44	45	46	48	50	51	52	53	54	Total
1	29	9		1				4	3	1		3		1	9	1	3	12			6		2	5	1			1	91
4		2						2				1			2			1		1	1	1							11
7		1													2		1	1			1		1						7
9																		2			1								3
11	1	1			2			1				1	1		1		2	1		1	1		1		1				15
12		1				2		2							2		2		1		1				1			1	13
13	2							4		2					3		1	2			3								17
14								22							3	1		2			1			2					31
15									1			2			1			1											5
18	2	2						2				2			3			5			1	1		1					19
19	1	1						2		2	1	5		2	1		3	7			4		1	5	4	1			40
21																		2			1								4
22	1		1					2	1			19			6		1	4			1	1		3				2	42
24	7	4				1		5				9	4		12	1	3	23		2	13	5	4	5	5	1		4	108
25			1														1												2
29	5	4						4	1		1	5			33		5	44		1	3	2	4	4	1				117
35												1			9	6		1					1	1	1	1			21
39	10	5						1	1			5		2	4	2	25	43	1	2	9		5	3	2	1		1	122
40	5	3						3		1		3	1	1	9	3	8	50		1	10	1	1	3	1			1	105
41								1				1				1		6			2		2	1					14
42	1	1	1					1				1			1		1	4			2				2	1			16
43	1							1												1									3
44	1							1							1			1		8				1				1	14
45	3	4	1			1		3				3		1	8		4	29			20		3	5				1	86
46				1	1	1		1	1						1		2	6			4	2	5						25
48	6							1	1			2			2	1	1	11			2	2	4	2				1	36
50	8	4						1				6	1	2	5	1	3	18		1	38	1	7	35		1		2	134
51	2	3			1		1	3				4			4		1	9			10			4	10			1	53
52	1							1							2		1	1			1		4	1	1	4			17
53		1								1					1					1				1			1	2	8
54	1							1		1								2			1							4	10
Total	87	46	4	2	4	5	1	69	9	8	2	73	7	9	125	17	68	288	2	19	137	16	45	82	30	10	1	22	1189

Table A.5: OD matrix for the evacuation trips by “Driving” (The number of trips between origin (horizontal) and destination (vertical))

	1	4	7	9	11	12	13	14	15	19	21	22	24	25	29	35	39	40	41	42	43	44	45	46	48	50	51	52	53	54	55	56	57	58	59	60	Total
1	538	82	1					2		2		7			18	4	5	8					8			6	7	2	2	1		107					800
4	37	39					1	1				2					1	3									1					4				4	93
7	10	18	13					27				1			1								3		34	3	2			1		8					121
9	8	16		6				21										1							6	1	1		1			8					69
11	5	4			3			12				1			2		2						1		7						6	4				1	48
12	2	5				3		20				1			3								1		7		1				28	4				7	82
13		4						14							2	1	1	1							4	3					23	3				1	57
14	1	1						142				2			8	1	2	2					2		98		1	1				42				1	304
15		1	1					73	9			16			2	1	1	1								1					4					11	121
18	4							1				43			1		2	1					1		1	4					13					17	88
19	1			1				2		6		146		2	3		3	3				4	2	1	1	2		2								16	195
21												6		13																					3	1	23
22	1							3				183		58	135		7	6				1	2	1		5	2								16	60	480
24	13	1					1	5		1		152	5	1	10	2	9	5				2	53	1	56	4	3	1		2	30					37	394
25	1							1						101	1	1	2							1	1	1	1		1						8		120
29	10	4	1	3			3	9	1	2		22	1	38	980	4	8	12	17				9	2	2	11	7	4	1	3					44	111	1309
35	3							1			1	25		25	32	12	2	1	39			22	3			5								3	8	5	187
39	9	1			1		2	8	1	1		3	1	1	18	1	83	92	161			260	7	2	1	11	7	2		284		74	52	7			1090
40	10							4	2	1		7	1	1	15	2	17	584					146	3	1	3	8	1		2		79		12		19	918
41	1					1								1	2		1	9	40			21				1	1							9	6		93
42			1											10	3			2	35	6		22			1	1	1							2	4		88
43															2		1		10		1	9								10				5			38
44	2	1						1							1			2				31	1	1		1				18				8			67
45	4	2	1					3	1			1	2	1	9	1	5	19	1	2		2	293	2	258	7	1					75				19	709
46	4			1				81				1			9		3	1	1	1			27	11	65	2	1	2				23					233
48	3	2						30				1			7	1	6	2					24		130	4	1		1			41					253
50	13	1	4			1		5	2			5	1	2	10	3	12	8		1		15	290	4	300	80	6			22		129					914
51	2		3			1		1		1		2	1		10	2	2	11				1	84	1	194	6	34	3		2		51					412
52	1							2				1	1	1	5	1	2	3					26		90	3	1	13				18					168
53								2				1			3				8			17							4	35			9	2			81
54								1				1		1			3	1				10					2			56			16				91
Total	683	182	25	11	4	6	7	472	16	14	1	630	13	256	1292	37	180	778	312	10	1	417	983	30	1257	165	89	31	10	436	104	670	77	48	89	310	9646

Table A.6: OD matrix for evacuation trips by “Walking” (The number of trips between origin (horizontal) and destination (vertical))

	1	4	7	9	11	12	13	14	15	19	22	24	25	29	35	39	40	41	42	43	44	45	46	48	50	51	52	53	54	55	56	57	58	59	60	Total
1	508	1				2		2	1	1	3	1		7		8	8		1			2		2	4	2	1		1		55					614
4	39	46						1						1		1						2				2					15					111
7		27	11							1				2										43	1	1					7					95
9	1	17		4				22			1																				8					53
11					2			26			1			3		1								1	2				1		2					39
12			1			4		11									2					3			2					24	8					55
13			1				2	10						2	1	1	2								1					16	3					39
14	3					2		215			1		1	3			4						2	2					2		36					273
15	1	1				1		57	2					4	2							1				1									5	75
18								1			44		1	3			1					2					1								9	62
19										7	101			1	1	2	2					2	1												21	138
21													22				1					1												4		28
22	1				1				1	2	217	1		7	1	2	2				2	2		1	4										27	271
24	2	1	2					3			1	3		3	5	1	4		2		1	237	1		3	5									43	317
25													66	3								1			1									6		77
29	8							2			2		1	89	9	5	603			1	1	1	2		7	6	1	1	1					94		838
35	3							1			1		1	44	13		2	54				3			4									13		139
39	6	1	1	2		1			3		5		1	9	4	52	265				219	4	2		5			2	1		54					639
40	5							3			1	1		12		7	568	4			2	2	3	2	7	3							77			713
41								1									15	25															10			51
42			2										17	3		1	1	28	3			1	1		1	1								5		64
43						1												11		4	7												5			28
44														2							18								22				3			45
45	2							3	1	2	2			8	5	6	6					408	2	1	6	2	1		1		79					535
46	2								1	1	1			2	1	1	1					1	8	91	4						16					130
48	1		2	1				2			1			2		6	7					1	1	167	5				1		27					228
50	7	1				1		4		1			1	12	2	8	9		1			412	1		38	2	4	2			66					574
51	2	1	2			1								5	1	4	6					262	1		5	23	2				32					347
52	1													3		3	1							81			13				17					119
53	1										1																	8	39			4				53
54			1					1						1			1						1					1	50			8				64
55																																				2
Total	593	96	23	7	3	13	2	365	9	15	383	6	111	231	45	109	1511	122	7	5	250	1348	26	391	100	48	23	14	119	40	425	12	95	122	105	6816