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Extensive application of a methodology to evaluate a tsunami-resilient transportation system

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MSc Civil Engineering T&P

Extensive application of a methodology to evaluate a tsunami resiliency of a transportation system

By

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I. Introduction

The resilience of infrastructure has gained increasing attentions recent years mainly because of inevitable natural disasters such as earthquakes and extreme rainfalls caused by the climate change, both of which could bring about catastrophic damages on societies in large. Having a more resilient infrastructure is assumed to minimize its loss since the concept entails both a strength (the ability to withstand an external shock) and a flexibility (the ability to bounce back) of infrastructures as a system, meaning that it not only reduces immediate impacts from a disaster but also it could reduce time to recovery after the disaster.

After the catastrophic event in Tohoku in 2011 where the tsunami destroyed many coastal communities following severe damages of an earthquake, Japanese government has applied this concept taking an initiative for "Building National Resilience" (2013) which has been practiced by municipalities throughout the country taking related measures. Looking at the related policy documents, however, while it intends to describe the concept of "resilience" accurately taking a broader socio-technical framework into account rather than just focusing on the robustness of infrastructures against a disaster, the assessment of the project appears to end up enumerating possible individual indicators related to resiliency of the communities and fail to provide the way to assess its overall resiliency of the communities or infrastructures. This seems to illustrate the fact that the concept is so comprehensive that breaking it down into measurable indicators is not simple.

A transportation system is one of the critical infrastructures for communities and the resiliency of the transportation system cannot be dismissed for any resilient communities. In case of a large-scale disaster like earthquakes, a transportation system plays an essential role in the whole series of events accompanied by the earthquake such as evacuations, rescues and reconstructions. There have not been much researches on the resiliency of a transportation system while parts of the resiliency have been studied extensively such as a vulnerability and a robustness. Among the limited studies on the resiliency of transportation system, developing methodologies to assess an overall resiliency of a transportation system quantitatively as well as qualitatively is one of the main areas as there has been no methodologies widely acknowledged. Making use of those knowledges, some authorities have carried out assessments in different ways to evaluate it and identify areas related to their transportation system to make it more resilient.

The objective of this research is to perform an analysis of an existing methodology, which evaluate the resiliency of a transportation network against an earthquake, through a case study in one of the coastal communities in Japan and to discuss its applicability to the different context such as a disaster type and a size of area. The methodology applied 16 variables and using a fuzzy inference approach those variables are converted into a total network resiliency. To achieve the objective, a site visit was carried out to gain knowledges about the area and to collect a set of data needed in the methodology in parallel with conducting a literature review. The data collected is national statistics, a response to questionnaires from the municipality and some general online information. While an attempt is made to collect the corresponding data to the methodology, modifications are made for reasons such as a lack of data. The principle is, however, not to change the variables to be measured but to change only the way to measure it. Once the result of resiliency is given using the data, a sensitivity analysis is made to investigate policies which could enhance its resiliency. Discussions are provided after that with regard to its applicability as well as areas of development for the future researches.

The reminder of this paper is organized as follows. In the next chapter, the literature review is provided including a description of the methodology applied for this study. In Chapter III, the case study location is explained briefly followed by Chapter IV in which the methodology is applied into the location using the collected data. The discussions are given from various perspectives in the following chapter before a conclusion in the final chapter.

II. Literature review

In this section, the literature review is provided mainly on assessments of the resilience of a transportation system including the one studied in this research.

A resilience is a socio-economic concept broadly interpreted to capture the ability to absorb shocks or disturbances to maintain its level of performance and, if degraded, to return to an equilibrium state. While the concept is closely related to the vulnerability defined as "the degree to which a system, or part of a system, may react adversely during the occurrence of a hazardous event" (Proag 2014), the resilience takes a longer time dimension into account being applied in the context of a rather severe or critical disruption. For such a disruptive event, a system at risk is expected to be capacitated not only physically but also institutionally or organizationally so that the damaged system can get recovered within a reasonable time frame.

A transportation system is one of many areas this concept can be applied and due to the growing concerns about unpredictable risks for example caused by the climate change researches around the concept has been increasing (Faturechi and Miller-Hooks 2014), the literature particularly on the resilience of a transportation system is, however, rather limited in contrast to abundant studies on the transport vulnerability where focuses are placed on transport network analysis (Mattsson and Jenelius 2015). Among those limited studies, a major interest is found in measuring or assessing the resilience of a transport infrastructure. Many studies base on or refer to a research by Bruneau et al. (2003) who present a conceptual framework to define the community resiliency in the face of an earthquake. The authors first introduced four principles to define the resilience; robustness, redundancy, resourcefulness, and rapidity, all of which contribute to the three key features for a system performance; "Reduced failure probabilities", "Reduced consequences from failures" and "Reduced time to recovery". Those measurements are further integrated into four dimensions; technical, organizational, societal, and economic, to complete the framework.

Hughes & Healy (2014) focused on two dimensions; technical (robustness, redundancy, safe-to-fail) and organisational (change readiness, networks, leadership and culture), assigning four level of scores into some measurements under each principle which are in turn weighted to an aggregate score for an overall resiliency. The assessment considered "An all-hazards" and "Specific hazard approach" depending on the context of the evaluation, which is an important perspective when dealing with any resiliency as risks sometimes are unpredictable. A real-scenario testing of the framework, however, is not undertaken due to the project constraints that it would take much more time and money to gather the data or the information for the assessment using the framework. Imran et al. (2014) propose a framework (Resilience Indicator Framework) to perform a holistic assessment of the resilience of a transport network in the Manawatu-Wanganui Region (NZ), taking six dimensions into accounts; engineering, services, ecological, social, economic and institutional. They conducted in-depth interviews to key stakeholders collecting some qualitative data in addition to some document analysis which helps identifying strengths and weaknesses in the region's transport network. This research, however, end up drawing a conclusion without comparable measurements which makes it impossible to apply to other transport networks.

van Dijk (2018) studied the tsunami-resiliency of a transportation system and decomposed the concept into different subjects in order to make it qualitatively evaluable. The resulting assessment method was applied to a case study in Oahu assessing each subject with five level of scales. While it provided insights in what factors influence the tsunami resiliency of a transportation system by detail analysis of the concept, it appears to have posed challenges in making the subjects measurable as the author chose to focus on one of the subjects, "ability to cope with disaster".

Heaslip et al. (2009) developed a framework to quantify and evaluate the resiliency of a transportation for a reginal network after disasters. The variables were devised using Maslow's hierarchy of need which starts from a foundation of physiological needs to the determination of self-actualization while considering Resiliency cycle of transportation from Normality to Recovery. (see Figure II-1)

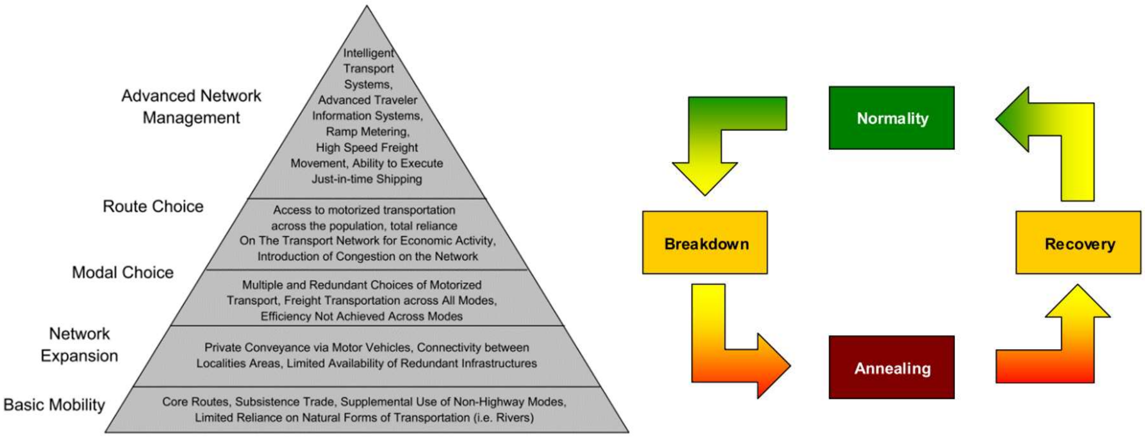


Figure II-1-Maslow's hierarchy of need (left) and Resiliency cycle of transportation (right) (Heaslip et al. 2009)

Applying this concept into the transportation context and four different levels of a resiliency; individual, community, economic and recovery, 16 metrics are presented as shown in Table II-1. As seen, some metrics are covered by more than one metric since those are considered applicable in different metrics. In this framework, a level of resilience is given on each level, which in turn comprise a total resiliency of a transport network of interest. While the framework was tested on a large region in the United States at a high level, the future enhancement of the framework was encouraged given that it has the potential to be applied to a smaller scale of a transport network.

Table II-1- Variables for transport resiliency (Heaslip et al. 2009)

	Variable	Metric
1	Mobility Index	Individual
2	Delay Encountered	Individual
3	Food & Medicine Index	Individual
4	Personal Transport Cost Index	Individual
5	Personal Mode Choice	Individual
		Community
		Economic
6	Network Redundancy	Community
7	Infrastructure Alignment	Community
8	Goods & Material Access	Community
		Recovery
9	Commercial Mode Choice	Community
		Economy
10	Industrial Mode Choice	Community
		Economy
11	Network Management	Community
12	Fuel & Energy Access	Economy
13	Commercial Transport Cost Index	Economy
14	Industrial Transport Cost Index	Economy
15	Emergency Response	Recovery
16	Resources Available	Recovery

There have been two papers dealing with this framework, one of which is the one evaluated in this study. The other one by Serulle et al. (2011) propose a methodology using a set of adjusted metrics based on it, performing a case study in Santo Domingo, the Dominican Republic. For the choice of the metrics, the approach is to stick to traditional measures of a transportation system performance, thus the metrics such as "Food & Medicine Index" or "Resources Available" are excluded. As shown in Figure II-2, the other metrics considered traditional transport measures are devised by separating a resiliency for infrastructures and users, making up "Base Resiliency", which is further combined with "Network Management" to define "Transportation Network Resiliency Index". Whereas the methodology seems to become more robust by focusing solely on those traditional transport measures which tend to be more accessible and comparable, it cannot be overlooked the fact that excluding non-traditional transport measures leaves out an important aspect of the resiliency, which is recovery. Considering the case of transport infrastructure being damaged by a disaster, the ability to restore it to pre-disaster level of service in a specified timeframe must form an essential part of resilience of communities which partly defines its transport infrastructure.

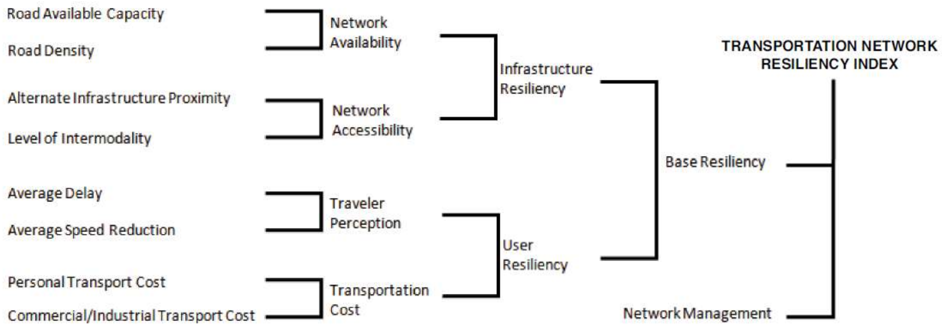


Figure II-2- Dependency diagram (Serulle et al. 2011)

The other one was done by Freckleton et al.(2012) who elaborated the framework such that it becomes applicable for a case study in Salt Lake City, the United States, assuming the city to be affected by an earthquake. Applying a fuzzy inference approach, each variable is given a qualitative scale, low, medium and high, depending on input values defined by the authors. Those scales are assigned numerical values, 1,2 and 3, or the inverse of it if the measurement and the resiliency are negative linear relationship, meaning that the higher the numerical value is the more it contributes to the resiliency. Each variable is attached to four metric groups just like the one presented by Heaslip et al. (2009); individual, community, economic and recovery. Some belong to more than one group while the others are attached to one of those. By design, the variables tied with more groups are given higher weights for the final total network resiliency expressed by values ranging from 0.33 to 1.00 with nine levels of resiliency. (see Figure II-3)

Variable	Measurement	Low	Medium	High
Mobility index	Level of service	E–F	C–D	A–B
Delay encountered	Travel time index	<1.13	1.13–1.15	>1.15
Food medicine index	(No. of locations/10,000 people)	≤2	2–4	≥4
Personal transport cost index	($/km)	<0.40	0.40–0.47	>0.47
Personal mode choice	Modes of transport	≤1	2	≥3
Network redundancy	(Arterial kilometers/km^2)	<2	2–5	>5
Infrastructure alignment	(kilometers)	<5	>15	5–15
Goods and material access	(No. of locations/10 km^2)	<0.5	0.5–1	>1
Commercial mode choice	Modes of transport	≤1	2	≥3
Industrial mode choice	Modes of transport	≤1	2	≥3
Network management	Level	I–II	II–IV	IV–V
Fuel and energy access	(No. of locations/10 km^2)	<3	3–6	>6
Commercial transport cost index	($/km)	<0.75	0.75–1.00	>1.00
Industrial transport cost index	($/km)	<0.75	0.75–1.00	>1.00
Emergency response	(hours)	>2	0.25–2	<0.25
Resources available	Disaster response contractors	<10	10–20	>20

- Extremely low: 0.33 ≤ 0.41
- Very low: 0.41 ≤ 0.48
- Low: 0.48 ≤ 0.56
- Medium low: 0.56 ≤ 0.63
- Medium: 0.63 ≤ 0.70
- Medium high: 0.70 ≤ 0.78
- High: 0.78 ≤ 0.85
- Very high: 0.85 ≤ 0.93
- Extremely high: 0.93 ≤ 1.00

Figure II-3- Variable input range definition (left) and Resiliency value range (right) (Freckleton et al. 2012)

This section illustrated that a resiliency of a transportation system is a complex concept hard to evaluate due to the wider scope taking socio-economic aspects into account. It seems that the more quantitative studies become the more difficult data collections get while the more qualitative methods it applies the less applicable the methods end up for different context. Freckleton et al.(2012) developed a well-balanced evaluation method between those two dilemmas based on the concept derived from Maslow's hierarchy of need and Resiliency cycle of transportation. This methodology, however, does considers an earthquake as a cause of system degradations but not a tsunami which bring about distinct consequences in communities.

III. Case study location

This section presents a case study location, where the methodology by Freckleton et al.(2012) is applied, describing the site itself as well as the site visit. In order to analysis the methodology from a tsunami-resilient perspective, the location which has actually experienced a tsunami was chosen so that the actual resiliency can be studied through the site visit in which their experiences are learned.

a. Site description

Otsuchi town is located in Iwate prefecture, the north-eastern Japan, whose coastal communities were severely damaged by the tsunami in 2011. The coastal line is characterized by ria coast, steep terrain, and shallow, narrow bays which also defines the divided shape of Otsuchi town. (Figure III-2)

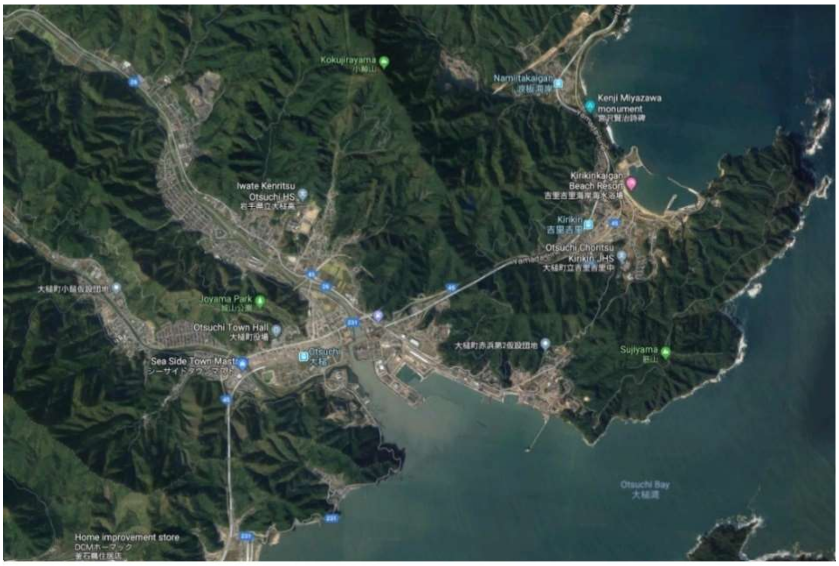


Figure III-2- Map of Otsuchi town (Google map)

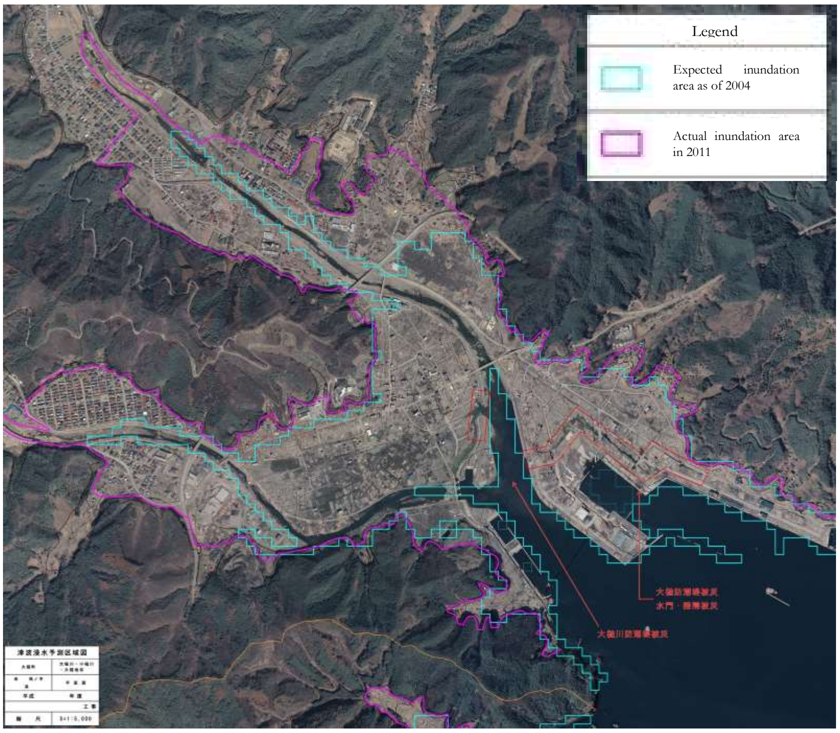


Figure III-1- Inundation areas of Otsuchi town (http://iwate-archive.pref.iwate.jp/tokusen/hazardmap/)

This geography allowed the tsunami waves get centred generating the unexpected run-up height. The tsunami caused nearly 10% of the population of the town to death or be missing and almost all the houses and buildings near the coastal area were swept away. (Mori et al. 2013) The first tsunami reached at their coastal line about 30 mins after the earthquake inundating 68% of the area designated for the land-use zoning.(Figure III-1) (Nakai 2013,Yamagawa et al. 2016) Some people evacuated from the lowland area up to the hillsides or further away from the coastal line on foot or by car while some remained being swept away. (Murakami et al. 2012)

A reconstruction plan was established the same year and there has been several projects implemented afterwards, most of which are supposed to be completed in 2019. The reconstruction plan includes some mega-infrastructure projects which would enhance the tsunami-resiliency of the community such as constructing a higher dike and land elevations. These measures are considered to reduce the probability of the area being inundated by the future tsunami. Measures which could enhance the tsunami-resiliency of transportation system have also been developed, in line with the concept of a sustainable transportation system, such as a new tunnel connecting two areas divided by the hill and widening a bridge. These measures are assumed to improve Network Redundancy and Infrastructure Alignment, and possibly Mobility index.

The current transportation network in Otsuchi town includes roads network, public/private bus systems, a port and a railway which is planned to be reopened in 2019. As found in Figure III-3, the road network consists of a national bypass 45 linking the town with neighbouring coastal communities (in red), three prefectural roads, 26, 231 and 280, running vertically and horizontally through the town (in yellow and orange), and local streets. Given the network and the facilities found alongside such as the town hall, the station and the shopping mall, the prefectural road 28 can be considered the arterial road used most by local people.

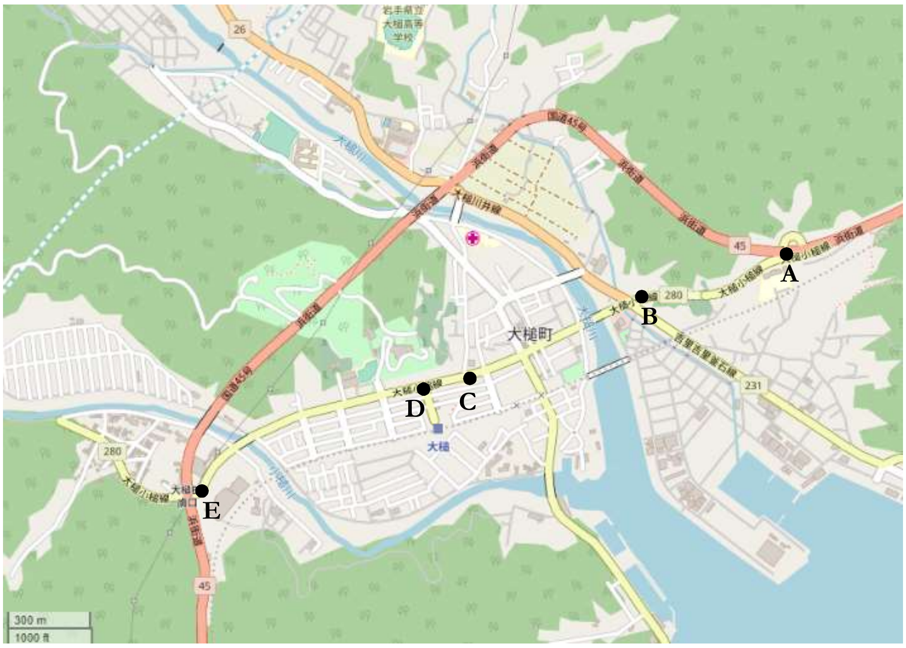


Figure III-3- Road map of Otsuchi town (OpenStreetMap)

b. Site visit

The site visit was realized with the help of Delft Deltas, Infrastructures & Mobility Initiative (DIMI) which encourages a multidisciplinary approach to solve societal problems related to critical infrastructures for water safeties and smart mobilities. The project was thus formed by researchers and students from different disciplines within two faculties, Architecture and Civil Engineering, with the aims of the collaboration among the disciplines to come up with innovative ideas to transform the urban deltas to changing conditions as a result of the climate change. Through some workshops and the site visit, each discipline contributes to exchanging ideas and knowledges which is unlikely gained within each discipline. During the site visit, in addition to the site tour guided by a local non-profit organization, opportunities were given to learn about the catastrophic event, the reconstruction and individual experiences from different people concerned.

Speakers from the governments spoke mainly about the damages by the disaster and the reconstruction plan. The local government presented their land use policy in which the concept of the tsunami resilience was taken into consideration. Identifying disaster hazard areas through tsunami simulations, residential areas at a higher risk of inundations were relocated to areas at a lower risk while some lands were elevated to make it less susceptible to tsunami. The regional government explained their responsible reconstruction projects, most of which require a rather regional perspective. Reconstructing roads and railroads was one of those since it is a wider network connecting one place to the others beyond a municipality. They were also responsible for reconstructing the seawall which was made double higher than the pre-disaster height making it unlikely to be overtopped by "more likely to happen" tsunami. With respect to the reconstruction process, some issues and difficulties were shared by the former mayor of the town who took the initiative in introducing a democratic decision-making process on the reconstruction project. The democratic process in addition to the bureaucratic process, the former mayor admitted, was one of the reasons why the reconstruction projects were prolonged. Hearing from local people such as a local non-profit organization and a high-school shed light on their evacuation behaviours which differed depending on multiple factors such their then locations, their household members and whether they were aware of designated evacuation spots. The summary of the hearings is found in Appendix 1

For a conclusion, as shown in the site description, the site location is small and has an odd shape, which partly define the transportation network as well as the impact of tsunami. This fact also indicates that the reconstruction projects related to the transportation to make the town more resilient required carefully studying the expected system degradation caused by a tsunami through the simulation. The site visit gave more insights into the reconstruction projects in which the different stakeholders were involved. For this unique-shaped place, attentions need to paid to both beyond the geography and the detail consequences such as individual travel behaviours given the disaster characteristics to study the resiliency of the transportation network.

IV. Application

This section is given to apply the methodology into the case study location in which 16 variables are evaluated using the collected data based on the principle that the same measurements are applied while if not possible due to some reason new measurements are suggested as a proxy. After the description of each variable, the result is presented followed by a sensitivity analysis to investigate policies which could enhance the resiliency of the transportation system in Otsuchi town.

a. Metrics

Mobility Index

Following the measurement by Freckleton et al, Level-of-service value outlined in the Highway Capacity Manual (Transportation Research Board 2000) is applied to define Mobility index for this study. Level-of-service is a qualitative measure to indicate a quality of transport infrastructures in terms of traffic conditions against its capacity. It is expressed by six levels ranging from level A to level F. HCM provides different methodologies to evaluate the level-of-service depending on a type of transportation facilities of interest. For this study, due to the data availability constraint, the prefectural road 280 found in Figure III-3 is chosen to be assessed using a methodology for "Urban streets". Firstly, a class of urban streets needs to be defined out of four classes (Appendix 2) according to HCM. Referring to Appendix 3 Appendix 4, the class for this street is assumed to be "II" based on the average speed, v/c ratio and the number of signals shown in Table IV-1 (see Figure III-3 for the segments). Table IV-2 then indicates that a type II urban street with an average speed of 37.3 km/h is categorized as "C", resulting in Medium.

Table IV-1- Traffic data of road 280 (National statistics 2015)

Start	End	Length [km]	Length Ratio	v/c ratio	Ave. Speed [km/h]	Ave. Speed* Length Ratio	Number of signal	Congestion
A	B	0.6	33.3%	0.69	50.4	16.8		0.69
C	D	0.2	11.1%	0.92	53.6	6.0	2	0.92
D	E	1	55.6%	0.92	26.2	14.5		0.92
		(Sum) 1.8		(Average) 0.84		(Sum) 37.3		

Table IV-2- Urban street LOS by class (HCM 2010)

Urban Street Class	I	II	III	IV
Range of free-flow speeds (FFS)	90 to 70 km/h	70 to 55 km/h	55 to 50 km/h	55 to 40 km/h
Typical FFS	80 km/h	65 km/h	55 km/h	45 km/h
LOS	Average Travel Speed (km/h)			
A	> 72	> 59	> 50	> 41
B	> 56–72	> 46–59	> 39–50	> 32–41
C	> 40–56	> 33–46	> 28–39	> 23–32
D	> 32–40	> 26–33	> 22–28	> 18–23
E	> 26–32	> 21–26	> 17–22	> 14–18
F	≤ 26	≤ 21	≤ 17	≤ 14

Delay Encountered

As the national statistics does not provide the corresponding data as the measurement by Freckleton et al., an assumption needs to be made using the available data. Applying Traffic Flow Theory, given the low-rate of flow for this bidirectional two-lane street (Table IV-3) and the average speed for this street whose speed limit is 40 km/h, the traffic condition could be assumed a free flow. That means

Table IV-3- Number of vehicles observed at the prefectural road 280 (National statistics 2015)

Direction	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
1	274	265	181	214	229	157	173	165	183	238	272	153
2	428	263	193	214	230	209	196	212	254	274	377	139

there is no delay encountered and the value is 1, thus applying the same measurement Freckleton et al. this variable is given Low.

Food Medicine Index

Applying the same measurement as Freckleton et al., there is a large hospital run by Iwate prefecture and a large supermarket in the town. In addition to this, the municipality has foods and medicines in store for emergency purposes, which could be counted in. Hence, Otsuchi town has approximately three locations per 10,000 people resulting in Medium for this variable.

Personal Transport Cost Index

Whereas Freckleton et al. used the then standard mileage rate for the use of a car, van, or pickup track for Personal Transport Cost Index, it is suggested for this research to use the ratio of expense of transport against their total monthly expenses at households, which can be easily found in the national statistics. The data is presented in Appendix 5. A drawback of using this figure is that the data is prefectural capital base and that it is combined with the expense of communications. However, given the assumption that the communication expense such as an internet and mobile phones is not affected by geographical location compared to that of transport, it can be considered that the difference of the ratio between the prefectures can be largely attributed to the transportation. It is beneficial for this variable to take the geography into account. The ratio is separated into three levels, Low (≤12%), Medium (12%<,<14%), High (≥14%), as those who cost the higher ratio of expense in transport are assumed to be more constrained, hence the transportation system is less resilient. Otsuchi town in Iwate falls in Medium.

Personal Mode Choice

Personal Mode Choice simply indicates the number of alternative modes which can be used in the case of one mode being unavailable. In Otsuchi town, in addition to personal automobile transportation, there are railway and bus.

Network Redundancy

Whereas Freckleton et al. referred the freeway and arterial road density, excluding local roads, to measure this variable, another measure is provided for this research as it does not seem appropriate to apply the same for Otsuchi town where the road network is way small. Xu et al. (2015) develop two quantitative measures to evaluate the transportation network redundancy; travel alternative diversity and network spare capacity. While the travel alternative diversity refers to the existence of multiple modes and effective routes, the network spare capacity deals with the network-wide residual capacity. These measurements are partly covered by the other variables; Personal Mode Choice for travel alternative diversity and Mobility index for network spare capacity. Thus, this variable could be measured by a multiplication of the two variables, High for the former and Medium for the latter, and due to the fact that Mobility index gets C, an upper level of Medium, High is given for this variable.

Infrastructure Alignment

Freckleton et al. applied the concept of primary and secondary infrastructure, but with the same reasoning as Network Redundancy, it does not seem appropriate to apply it for Otsuchi town. Hence a new measurement is provided using a road classification. According to The Federal Highway

Table IV-4- Road classification by FHA

Functional System	Services Provided
Arterial	Provides the highest level of service at the greatest speed for the longest uninterrupted distance, with some degree of access control.
Collector	Provides a less highly developed level of service at a lower speed for shorter distances by collecting traffic from local roads and connecting them with arterials.
Local	Consists of all roads not defined as arterials or collectors; primarily provides access to land with little or no through movement.

Administration in the US, there are three functional classifications; arterial, collector, and local roads.(Table IV-4)

Applying this classification into Otsuchi town, it can be considered that the national road 45 is Arterial, the prefectural road 280 and 26 are Collector, and the rest of streets are Local. Despite those different functions, due to the size of the town, the distance between those roads seems so close that they could not be considered alternative routes to each other as all the routes are likely subject to the impact of a tsunami. This appears to be a critical aspect of the resiliency of a transportation system in coastal communities. Considering the characteristics of impacts given by a tsunami, the most desirable road could be the one running vertically against a coastal line as it could be an access to and from tsunami-free areas. In fact, the recovery for such vertical roads were prioritized over the coastal roads as emergency services were provided from unaffected inland cities.(Yoshizaki 2011) In case of Otsuchi town, it is the prefectural road 26 that connects the town with the inland, but it is not a high-quality national road as opposed to those prioritized roads found in the neighbouring cities like Miyako and Kamaishi. Nevertheless, it is better than nothing like Yamada town, about 13 km up to the north of Otsuchi. Hence, it is suggested that Infrastructure Alignment is High if there is such a high-quality vertical road against coastal line, Medium if there are any other kinds of bidirectional road and Low otherwise. Thus Otsuchi town is classified Medium.

Goods & Material Access

According to the municipality, it is considered that road damages caused by a disaster could not be repaired by resources in Otsuchi town, thus they need to receive assistances from The Japan Self-Defense Forces in that case. Applying the same measurement as Freckleton et al., this variable is given Low.

Commercial Mode Choice

Similar to Personal Mode Choice, but the railway line in Otsuchi is not used for a freight transport and a bus is not applied, so only a truck is an option available. Thus this variable gets Low.

Industrial Mode Choice

In addition to the truck applied for Commercial Mode Choice, ports can be included for this variable which accounts for more than 40% of freight transport in volume (Sugiyama 2010). Otsuchi town therefore has two modes available, receiving Medium for this variable.

Network Management

Applying the five level of the network management of the methodology, that of Otsuchi town would be Level 2 which is classified as Low since the town is equipped only with conventional traffic signals.

Level 1. Police officers directing traffic,
Level 2. Traffic signals,
Level 3. Dynamic traffic signals timing and ramp metering,
Level 4. Traffic cameras and variable message signs,
Level 5. Intelligent transportation systems and advanced traveller information system.

Fuel & Energy Access

The municipality has made agreements with two local institutions dealing with oils that they would provide fuels in case of a disaster. Following the measurement by Freckleton et al and limiting the area to the downtown area of about 5 km^2, Fuel & Energy Access falls in Medium.

Commercial Transport Cost Index

Similar to Personal Transport Cost Index, this variable presents the cost for commercial entities. Since there is no relevant statistics data available, a new measurement is suggested as a proxy. It is a fixed cost of a delivery service between the regions of Yamato Transport Co., Ltd. which is one of three major door-to-door delivery service companies whose market share is nearly 50%. Summing all the fee of a small package being sent from one region to the other (Appendix 5), it indicates that the farther the region is away from the major three cities, Tokyo, Osaka and Nagoya, the more expensive the fee is incurred, which is intuitively reasonable for this variable. Same as Personal Transport Cost Index, three levels are given; Low (≤13000), Medium (13000<,<16000), High (≥16000) and Otsuchi town in Kita Tohoku falls in Medium.

Industrial Transport Cost Index

In contrast to Freckleton et al. applying the same value as Commercial Transport Cost Index, for this research, a different measurement is suggested given the assumption that industrial goods are more associated with global markets. This could mean that industrial transport performance in Otsuchi town benefits also from the competitiveness of that of the country. According to the World Bank, Japan is ranked in the top 5 out of 160 countries in the Logistics Performance Index in 2018. Although the commercial transport cost could also contribute to this variable, considering the very high competitiveness of the country's performance, Low is given to this variable.

Emergency Response

Due to the size of the town, Otsuchi town is not capacitated with a self-response system for a disaster. The municipality assumes that the assistance from the inland area could be made the following day while in reality it took two days for the assistance to be made in 2011 Tōhoku earthquake and tsunami. The measurement by Freckleton et al therefore places it Low.

Resources Available

Freckleton et al. referred to the number of licensed disaster response contractors registered by the U.S. Army Corps of Engineers to quantify this variable. Since there is no corresponding information available for Otsuchi town, a different measurement is suggested for this research in which two factors are considered. One is taken from the result for "Goods & Material Access" and the other is whether the municipality has established "Chiiki bōsai keikaku", local disaster prevention plan, backed by a national law. In this plan, municipalities define responsibilities and cooperation for a disaster prevention, response and reconstruction in collaboration with local institutions dealing with critical infrastructures. Otsuchi town has established their plan in 2018. This variable is therefore given Medium as a result of Low for "Goods & Material Access" and the disaster prevention plan.

Summary

The summary is presented in Table IV-5 in which the results for each variable are highlighted in red. It also provides whether modifications are made on the way it is measured and whether the values should be given inversely because of the negative linear relationship between the variables and the resiliency.

Table IV-5- Summary of the resulting measurements

Variable	Measurement	Low	Medium	High	Modification	Inverse
Mobility Index	Level of service	E-F	C-D	A-B		
Delay Encountered	Travel time index	<1.13	1.13 - 1.15	>1.15	○	○
Food & Medicine Index	(No. of locations/10,000 people)	≤2	2-4	≥4		
Personal Transport Cost Index	Monthly transport expense over the overall expense at households	≤12%	12% - 14%	≥14%	○	○
Personal Mode Choice	Modes of transport	≤1	2	≥3		
Network Redundancy	Personal Mode Choice * Mobility Index	Low * "D/E/F" Medium * "F"	Low * "A/B/C" Medium * "B/C/D/E" High * "D/E/F"	Medium * "A" High * "A/B/C"	○	
Infrastructure Alignment	Existence of roads running vertically running against coastal lines * High-quality or not	No exist	Exist but low quality	Exist and high quality	○	
Goods & Material Access	(No. of locations/10 km^2)	<0.5	0.5 - 1	>1		
Commercial Mode Choice	Modes of transport	≤1	2	≥3		
Industrial Mode Choice	Modes of transport	≤1	2	≥3		
Network Management	Level of service	I - II	II - IV	IV - V		
Fuel & Energy Access	(No. of locations/10 km^2)	<3	3 - 6	>6		
Commercial Transport Cost Index	Delivery cost between the regions	≤13,000	13,000 - 16,000	≥16,000	○	○
Industrial Transport Cost Index	Commercial Transport Cost Index * Logistics Performance Index	Low * "1-80" Medium * "1-20 "	Low * "1-80" Medium * "21-140" High * "81-160"	Medium * "141-160" High * "81-160"	○	○
Emergency Response	(hours)	>2	0.25 - 2	<0.25		
Resources Available	Goods & Material Access * Existence of local disaster prevention plan	Low * No exist	Low * Exist Medium * Either exist or not exist High * No exist	High * Exist	○	

b. Result and sensitivity analysis

After assigning the values based on the levels and the positive or negative relationship between the measurement and the resiliency, the metric resiliencies are calculated using different weights depending on the number of variables for each metric. For example, as Delay Encountered is negative liner relationship with the resiliency, the level of Low gets 3. Then, dividing the value by the number of variables for Individual, 3/5, the weighted value for Delay Encountered becomes 0.6. Summing up all the weighted value under a metric and divide it by 3 is a metric resiliency. (e.g. 2.4/3=0.8 for Individual) All the metric resiliencies are also weighted by ¼ and the sum of the four values is the total resiliency.

Result

The result is presented in Table IV-6. As shown, individual values are weighted by the number of variables belonging to each metric while the metric resiliency is defined by equal weights of each metric which in turns leads to the total resiliency by its summation. Referring to the stratification of resulting values by Freckleton et al., total network resiliency in Otsuchi town falls in Medium with 0.66, which is ranked fifth out of ninth levels. Looking at the metrics, it should be noted that the metric resiliency for Recovery is quite low which offsets the high scores for Individual, leading to the total resiliency much lower than that of Salt Lake City studied by Freckleton et al. This result seems to be attributed to the size of town where budgets are generally constrained more than cities. It can be assumed that the transport network for daily use can be well designed and maintained in spite of this small size of the town, but taking rare events like a large-scale disaster into account for transport resiliency can remain to be challenging.

Table IV-6- Result of the application

Metric	Measurement	Level	Value	Weighted 1	Metric Resiliency	Weighted 2	Total Resiliency
Individual	Mobility Index	Medium	2	0.40	0.80	0.20	0.66
	Delay Encountered*	Low	3	0.60			
	Food & Medicine Index	Medium	2	0.40			
	Personal Transport Cost Index*	Medium	2	0.40			
	Personal Mode Choice	High	3	0.60			
Community	Personal Mode Choice	High	3	0.43	0.67	0.17	
	Network Redundancy	High	3	0.43			
	Infrastructure Alignment	Medium	2	0.29			
	Goods & Material Access	Low	1	0.14			
	Commercial Mode Choice	Low	1	0.14			
	Industrial Mode Choice	Medium	2	0.29			
	Network Management	Medium	2	0.29			
Economic	Personal Mode Choice	High	3	0.50	0.72	0.18	
	Commercial Mode Choice	Low	1	0.17			
	Industrial Mode Choice	Medium	2	0.33			
	Fuel & Energy Access	Medium	2	0.33			
	Commercial Transport Cost Index*	Medium	2	0.33			
	Industrial Transport Cost Index*	Low	3	0.50			
Recovery	Goods & Material Access	Low	1	0.33	0.44	0.11	
	Emergency Response	Low	1	0.33			
	Resources Available	Medium	2	0.67			

* Inverse order is applied

Sensitivity analysis

Sensitivity analysis can be made for recommendations assuming policies which could enhance the transport resiliency by improving areas of the variables. Three transport policies and a set of non-traditional transport measures which are assumed to improve the transport resiliency are tested and the result is summarized in Table IV-7.

1. *New tunnel*

   One of the measures planned by the municipality is to connect two separated communities along the two rivers running inland by a tunnel (Figure IV-1). This tunnel could potentially increase Network Redundancy, Infrastructure Alignment and Mobility Index. The measurement of two of them except Network Redundancy have spaces to be increased and the resulting resiliency is 0.69.

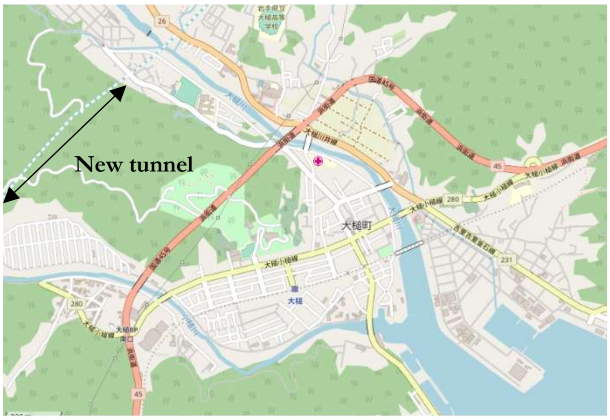


Figure IV-1- New tunnel planned by the municipality

2. *Freight railway transport*

   As mentioned previously, the railway line is not used for a transport but only for a passenger transport. Adding the freight transport function to the railway line would not only increase the mode choice for commercial and industrial purposes but also decrease the transport cost for those purposes, leading to higher resiliency of transportation system with 0.72.

3. *Prefectural road 26*

   Upgrading the prefectural road 26, which is currently not high-quality, that connects the town with the inland could improve its resiliency from several perspectives. This improvement could directly or indirectly improve Network Redundancy, Infrastructure Alignment, Goods & Material Access, Emergency Response and Resources Available. Except for Network Redundancy which is already High, making the other measurements one level up would increase the total resiliency to 0.77.

4. *Non-traditional transport measures*

   Non-traditional transport measures could be taken through, for example, a cooperation with external parties. Some goods like foods and fuels or even road repairment materials for emergency purposes could be stored in collaboration with neighbouring municipalities. By concluding an agreement with non-coastal municipalities like Tono city for emergency services, the time and the extent of delivering those services could be improved which are related to some measurements especially under "Recovery". Such a measure tend to be inexpensive compared to the infrastructure projects but could possibly be more effective to enhance the resiliency thanks to the well-preparedness. Improving the measurements for 5 variables, Food & Medicine Index, Goods & Material Access, Fuel & Energy Access, Emergency Response and Resources Available turns out to be the highest resiliency with 0.78 leading to the total resiliency with High.

Table IV-7- Result of the sensitivity analysis

	Initial	1. Tunnel	2. Freight	3. Road 26	4. Non-traditional
Community	0.80	0.87	0.80	0.80	0.87
Economic	0.67	0.71	0.76	0.76	0.71
Individual	0.72	0.72	0.89	0.72	0.78
Recovery	0.44	0.44	0.44	0.78	0.78
Total	**0.66**	**0.69**	**0.72**	**0.77**	**0.78**

Although about a half the measurements are subject to the changes, all the variables are measured successfully enabling to evaluate the current resiliency of the transportation system. The result shows that the resiliency of the tranpsortation system is Medium and that a metric of Individual gives a positive value while that of Recovery indicates a room of improvements.Through the sensitivity analysis, some measures related to one or more of the variables are tested showing non-infrasturucture projects can enhance the resiliency better than the conventional transport projects. Adding what's learned during the site visit to this application provides an insight into how well this methdology peformed to evaluate the resiliency of transportaion system in diffrenet contexts which is discussed in the next chapter.

V. Analysis and discussions

In this chapter, analyses are made as to whether the methodology by Freckleton et al. is to what extent applicable in terms of data collection, different size of area, and lastly but more importantly the type of disaster "tsunami". After those analyses, suggestions are given to improve the methodology followed by a broad discussion from a transportation perspective.

a. Data collection

As seen in the previous chapter, some modifications are made to the measurements in order to apply it to Otsuchi town as some data are not publicly available. Eight measurements are subject to it and alternatives are provided to quantify those variables. While collecting the data for some of them should not be too difficult such as travel time or level of service, Resources Available for example uses the data particular to cities in the U.S. and that kind of data seems not available in other countries. Finding different kinds of transport costs could also be challenging as implied by the fact that the methodology itself applied the same cost both for Commercial and Industrial Transport cost which seems not reasonable. Nevertheless, while applying the exact same measurements might not be always possible, the data for most of the measurements are available or obtainable. Network Redundancy and Infrastructure Alignment are for example measured in simple ways that a data collection can be made just using a geographical information. Some non-traditional transport measures such as Food Medicine Index or Fuel & Energy Access also use accessible data. The overall applicability from the data collection perspective therefore seems one of the major contributions of this methodology.

b. Size of area

As mentioned in the literature review, other than the case study by Freckleton et al. in Salt Lake City, similar methodologies have been applied for a reginal transport network in the US (Heaslip et al 2009) and Santo Domingo (Serulle et al. 2011), but those areas are way larger than Otsuchi town. For this reason, some measurements could not be applicable simply by seeing it a relative difference, and another measurements or different thresholds may need to be introduced, which requires another scientific foundations to define. Network Redundancy defined by a road density by km per km², for example, is possible to get the data, in case of small areas however how those roads are connected seems also important. In case of Otsuchi town, only the national road and the arterial road are considered and they run in parallel getting converged at both side of the town . In this context, whether they enhance redundancy could be questioned because once those two connected points are destroyed, both roads would stop functioning. Moreover, with respect to Infrastructure alignment where the average distance between primary and secondary infrastructures is considered, the area seems too small to simply separate primary and secondary infrastructure defining its alignment. For this reason, the alternative measurement was suggested in this study.

c. Disaster type

While the type of disaster assumed to define the variables is not specified in Heaslip et al., Freckleton et al. assumed for the case study an earthquake and check the resulting resiliency against Modified Mercalli Intensity (MMI) which is an abbreviated description of the 12 levels of seismic intensity (Figure V-1). In case of Otsuchi town with the medium resiliency, it is estimated that the town should withstand a Level 7 event without a significant disturbance to the transportation network. In case of applying JMA seismic intensity scale which is widely used in Japan, a research needs to be performed as done by the University of Utah to identify the relationship between the scales and the resiliency resulting in the graph.

This methodology is, however, unlikely to be applicable for the case of tsunami where the way it damages an area and the way people deal with are different from an earthquake. In most cases, tsunami is caused by earthquakes so an area can get damaged more severely than the solo case of earthquake, and moreover the way an area inundated could be tricky as it depends on the geography and the vertical/horizontal distance from the sea in addition to the intensity of its cause. This could be partly improved by substituting a tsunami intensity for MMI. Imamura et al. (2001), for example, suggested a new tsunami intensity scale which is consistent with the several twelve-grade seismic intensity scales widely acknowledged in North America and Europe such as MMI.

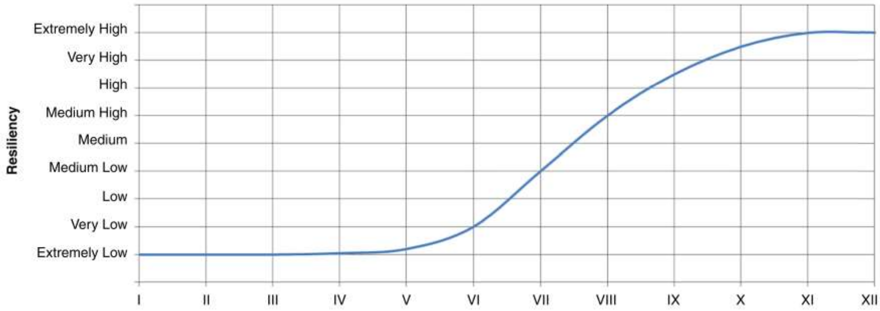


Figure V-1- Modified Mercalli Intensity (Freckleton et al. 2012)

Furthermore, the way people evacuate from the affected area has different manners to that of earthquake. People encountered earthquake would evacuate from the area after the event occurring for a fear of secondary disasters such as building collapses and fires, and open spaces found in different parts of area can be evacuation points. In case of tsunami, on the other hand, people tend to get alarmed prior to the arrival of tsunami having certain amount of time to evacuate, but they need to be away vertically and/or horizontally from the sea. This part of whole dimension, evacuation, dealing with resiliency has a lot to do with a transportation system as how easy and fast people evacuate from one point to the other is crucial to minimise a human loss. For this part, in addition to the conventional transport related measures such as Mobility index, it could be suggested to consider the number and proximity of evacuation points, the alarming system or whether municipalities establish an evacuation plan or not.

d. Suggestions

Whereas the disaster type can be partly compensated by the tsunami intensity scale, it should be noted that the probability of areas getting affected is still left out as those intensity scales refer the consequence actually experienced at an area regardless of its probability. Because of this, the methodology is not capable of taking into account the major measures Otsuchi town has taken to enhance the resiliency of community; the higher dike, the land elevation and restructuring land use adjacent to the coastal line. These measures are meant to reduce the probability of the populated areas being inundated in case of tsunami and thus the transportation system also becomes less likely to be inundated. This is the first of the three key features for the system performance explained in the literature review; "Reduced failure probabilities", "Reduced consequences from failures" and "Reduced time to recovery". A solution to this can be referred to van Dijk (2018) which included "Location of an infrastructure component" in the assessment using an inundation map. Nevertheless, although there could be an increasing number of cities which have created such maps given the development of tsunami forecasting technologies, it could undermine the advantageous well-simplified method of the methodology in case of cities not having such maps. This part could be further studied in the future research.

One more thing that could be discussed is the threshold set for each measurement defined by the authors with rough explanations. Once areas of interest are set in different countries or cities with different size or context, distinct thresholds need to be suggested based on scientific foundations, making the methodology less transferable. In this matter, making a ranking-based threshold can be applied as done for the transport costs in this research. While this can be applied within a country or region where the same information is available, it gives relative performance within the territory, without scientific foundations, helping to identify weak areas in their context.

e. Transportation

Unlike the above-mentioned analyses from the specific perspectives, the methodology can be discussed rather from a transportation domain. As explained in the literature review, the methodology was developed using Maslow's hierarchy of need in case of a transportation system. Here a discussion is provided referring to Wegener's circle which describes interactions between a transportation system and a land use mainly consisting of Transportation system, Accessibility, Land use and Activities. (Figure V-2)

Same as the normal condition, tips under a disrupted situation are made by a series of choices such as destination choice and mode choice (see "Demand" in the figure). Those choices are made by different factors such as travel time, distance and cost, and of course those choices are constrained by available choices. This aspect is well captured in the methodology by the transportation-related variables such as Mobility Index, Mode Choice and Transport Cost. What could be added here to distinguish it from the normal condition is, as elaborated previously, the demand of trips for the evacuation and rescue whose trip choices are affected by different factors from the normal one. On the other hand, what is also important when dealing with the resiliency of a transportation system is to considerer a degradation of the system caused by a breakdown (see "Supply" in the figure). By including some non-transportation variables such as Good & Material Access and Fuel & Energy Access which are important components for most transportation systems, the methodology becomes more robust to evaluate the resiliency. Lastly, "Land use" part of Wegener's circle reminds an important aspect of the resiliency always difficult to measure. As found during the site visit, the reconstruction projects of Otsuchi town were delayed because it required a long period of time for the involved countless decisions including about the land use, and those delays affected the people's decision to not come back to the town, resulting in probably less expected activities. This without a doubt could affect the transportation planning such as the bus and railway services dependent on the demand. Taking these aspects into account in a methodology for the resiliency of a transportation system is a highly multidisciplinary and challenging task.

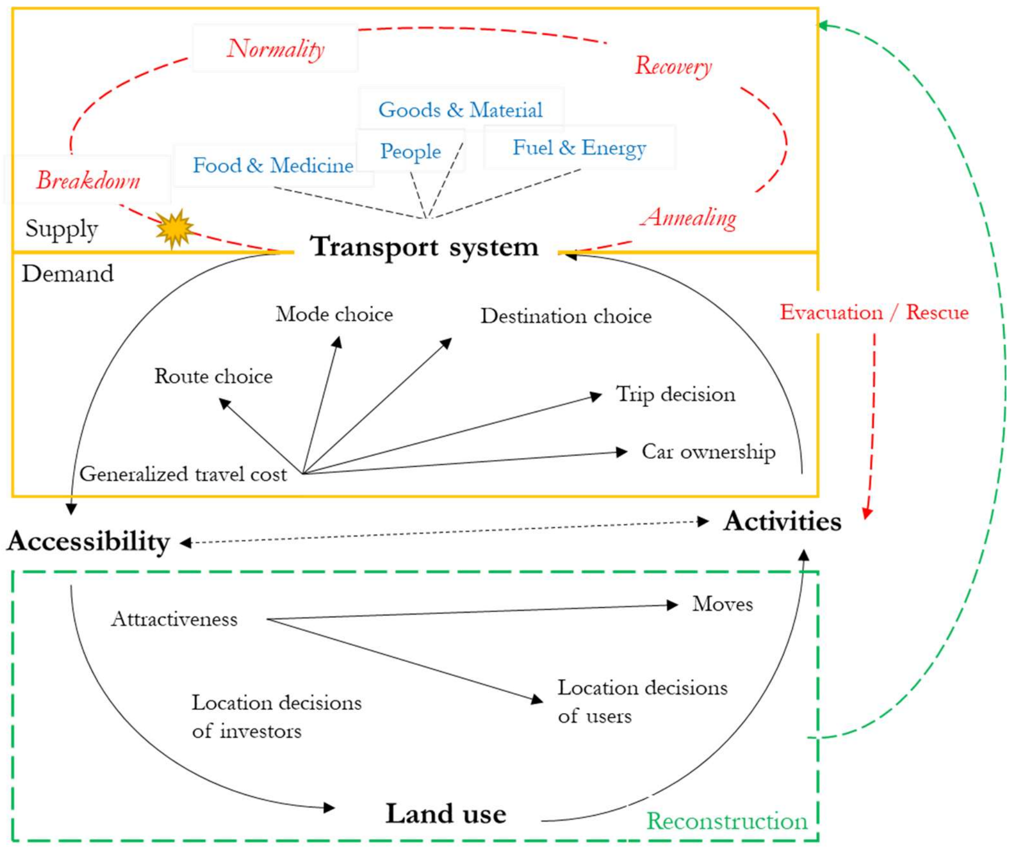


Figure V-2- Wegener's circle with the resiliency of a transportation system

VI. Conclusions

By the case study on the location considerably distinct from the previous studies, the methodology was tested whether it is applicable into different contexts. The variables to be measured to define the resiliency of transportation network was kept while some modifications were made, due to the lack of corresponding data, as to how to measure the variables. The result was provided indicating that the total network resiliency of Otsuchi town is Medium and that some improvements could be made especially in the area of Recovery. Based on the result, the sensitivity analysis was made assuming various policies which would improve the measurements of some variables. The results suggested a possibility that non-infrastructure projects could enhance better the resiliency than conventional transport projects.

The case study provided insights into the applicability of the methodology which was discussed from several perspectives. It showed a decent tractability from data collection perspective applying straightforward measurements to successfully controlled number of variables. With respect to the size of area, on the other hand, it seems to have posed questions on a couple of measurements such as Network Redundancy and Infrastructure Alignment where the size difference could not be dealt simply with a relativity. As a solution for this matter, since both variables deal with alternative routes, the two variables can be combined to develop a new variable looking into whether the area has routes for evacuations to other areas. The aspect of evacuations is related to the applicability from the type of disaster perspective as it could be a major contribution of transportation systems in case of the tsunami-resiliency. To extend the methodology to the case of tsunami, therefore, how easy and fast people evacuate from one point to the other could be added as a new variable. Also, one simple solution was suggested from the disaster type perspective to substitute a tsunami intensity scale for MMI. As potential developments of the methodology which require further researches, two things were provided. One is to take "Reduced failure probabilities" into account to capture extensively the feature of the system performance and the other is to introduce a ranking-based threshold to make the methodology more applicable in different contexts. The discussion using Wegener's circle confirmed not only the relevancy of the methodology from the transportation perspective but also the challenge to assess the resiliency of a transportation system.

Appendix

Appendix 1- Summary of the meetings

Date	Speakers	Remarks
Sep 17th	Local junior and high school students	Three students spoke about their experiences on the day of the event and the following days and shared their views towards the reconstruction. It was found that their experiences and views were very different depending on where they were, their family circumstances, their future plan and so on, which provided an insight into mixed feelings among the victims.
Sep 18th	Municipality of Otsuchi town	The officer explained mainly about the damage caused by the event and their local reconstruction projects sharing procedures, issues and technical aspects. It was notable that a vast amount of investments has been poured into this small town where there is only limited number of officers are engaged in, most of whom suffered themselves by the event causing a lot of stress on them. They have managed to proceed a number of different projects taking civil engineering constraints into account while dealing with administrative and democratic procedures, which took a lot of time and efforts.
	Prefectural government of Iwate	The officer presented the consequence of the disaster from their wider perspective covering those of other coastal municipalities. Also, they explained about the regional reconstruction where they have played a vital role particularly in the area of transportation such as regional road network and railways. It was confirmed that the resiliency of a transportation system in Otsuchi town is largely dependent on the regional transport network as it is meant to be used for evacuation, rescues and reconstruction itself. The progress of the projects, however, was found not to be satisfactory from the fact that only 49% of the previous road network has been recovered and that a railway running along their coastal line is finally reopening after seven years. The reason was not clearly stated but it could be partly due to the declining and ageing population making it rather difficult to justify investments to return the infrastructure to the pre-disaster state.
Sep 19th	Former mayor of Otsuchi town	The former mayor, who took office months after the disaster at the municipality which lost the previous major by the event, spoke about the making of reconstruction plan to which he made a great effort. He took an initiative to realize unconventional policies such as a democratic decision making and a monumental nature-based sea wall. It should also be noted that he was devoted to emphases the importance of learning from their experiences to develop the disaster management which is, he says, their responsibility for the future generation possibly facing the next disaster.
	Local NGO	The director of a local NGO, which strives for a locally-engaged sustainable economy through a forestry, told the story of his life after the disaster which affected his views of life. The unimaginable scale of the nature force he experienced made him become aware of the greatness of the mountains which stayed unchanged after the event.

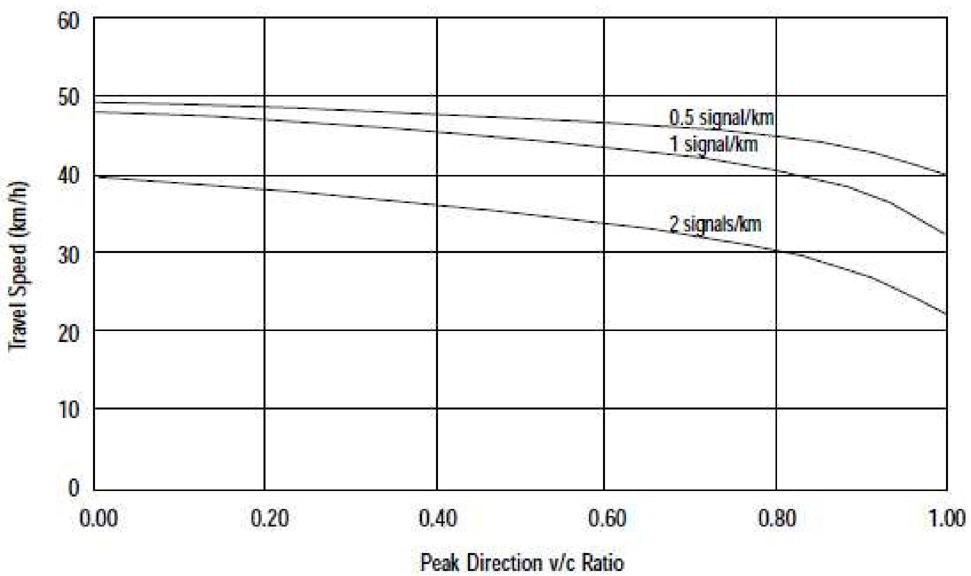
Appendix 2- Urban street class based on functional and design categories (HCM)

Design Category	Functional Category	
	Principal Arterial	Minor Arterial
High-Speed	I	N/A
Suburban	II	II
Intermediate	II	III or IV
Urban	III or IV	IV

Appendix 3- Free-flow speed by urban street class

Urban Street Class	Default (km/h)
I	80
II	65
III	55
IV	45

Appendix 4- Speed-flow curves for class II urban streets



Appendix 5- Monthly household expense (National statistics 2017)

Region	Prefecture	Total Monthly Expense	Tranport & Communication expense	Ratio
Hokkaido	Hokkaido	222,421	29,897	13.4%
Tohoku	Aomori	189,098	23,426	12.4%
	Iwate	245,924	31,722	12.9%
	Miyagi	206,199	27,004	13.1%
	Akita	214,852	27,186	12.7%
	Yamagata	255,697	38,158	14.9%
	Fukushim	275,447	40,022	14.5%
Kanto	Ibaraki	262,295	42,295	16.1%
	Tochigi	263,505	32,918	12.5%
	Gunma	243,681	34,949	14.3%
	Saitama	244,158	29,122	11.9%
	Chiba	240,770	38,642	16.0%
	Tokyo	277,198	27,863	10.1%
	Kanagawa	260,400	26,855	10.3%
Chubu	Niigata	229,838	33,775	14.7%
	Toyama	253,726	35,400	14.0%
	Ishikawa	271,600	36,703	13.5%
	Fukui	241,919	28,173	11.6%
	Yamanashi	235,252	30,967	13.2%
	Nagano	275,572	41,272	15.0%
	Gifu	240,329	34,868	14.5%
	Shizuoka	248,997	28,617	11.5%
	Aichi	233,471	27,449	11.8%
Kinki	Mie	274,595	34,357	12.5%
	Shiga	253,681	32,595	12.8%
	Kyoto	242,330	28,643	11.8%
	Osaka	221,534	24,680	11.1%
	Hyogo	211,871	26,056	12.3%
	Nara	297,981	40,895	13.7%
	Wakayama	244,934	33,173	13.5%
Chugoku	Tottori	199,797	26,314	13.2%
	Shimane	233,633	35,749	15.3%
	Okayama	237,597	31,196	13.1%
	Hiroshima	223,412	26,898	12.0%
	Yamaguchi	221,733	32,267	14.6%
Shikoku	Tokushima	216,863	26,700	12.3%
	Kagawa	273,973	42,196	15.4%
	Ehime	246,824	32,770	13.3%
	Kochi	251,474	33,227	13.2%
Kyushu	Fukuoka	241,396	33,556	13.9%
	Saga	212,609	27,871	13.1%
	Nagasaki	208,679	25,944	12.4%
	Kumamoto	223,307	25,057	11.2%
	Oita	235,021	34,808	14.8%
	Miyazaki	224,474	30,676	13.7%
	Kagoshima	237,348	35,078	14.8%
	Okinawa	187,338	24,833	13.3%

Appendix 6- Delivery cost across regions for small package of Yamato Transport Co., Ltd (Nov 2018)

		From											
		Hokkaido	Kita Tohoku	Minami Tohoku	Kanto	Shinetsu	Hokuriku	Chubu	Kansai	Chugoku	Shikoku	Kyushu	Okinawa
To	Hokkaido	907	1,123	1,231	1,339	1,339	1,447	1,447	1,663	1,771	1,771	1,987	1,987
	Kita Tohoku	1,123	907	907	1,015	1,015	1,123	1,123	1,231	1,339	1,339	1,555	1,663
	Minami Tohoku	1,231	907	907	907	907	1,015	1,015	1,123	1,339	1,339	1,555	1,555
	Kanto	1,339	1,015	907	907	907	907	907	1,015	1,123	1,123	1,339	1,339
	Shinetsu	1,339	1,015	907	907	907	907	907	1,015	1,123	1,123	1,339	1,447
	Hokuriku	1,447	1,123	1,015	907	907	907	907	907	1,015	1,015	1,123	1,447
	Chubu	1,447	1,123	1,015	907	907	907	907	907	1,015	1,015	1,123	1,339
	Kansai	1,663	1,231	1,123	1,015	1,015	907	907	907	907	907	1,015	1,339
	Chugoku	1,771	1,339	1,339	1,123	1,123	1,015	1,015	907	907	907	907	1,339
	Shikoku	1,771	1,339	1,339	1,123	1,123	1,015	1,015	907	907	907	1,015	1,339
	Kyushu	1,987	1,555	1,555	1,339	1,339	1,123	1,123	1,015	907	1,015	907	1,231
	Okinawa	1,987	1,663	1,555	1,339	1,447	1,447	1,339	1,339	1,339	1,339	1,231	907
		18,012	14,340	13,800	12,828	12,936	12,720	12,612	12,936	13,692	13,800	15,096	16,932

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