DISSERTATION

QUANTITATIVE STUDY ON NATURAL DISASTERS RISK MANAGEMENT POLICY

- APPLYING STATISTICAL DATA ANALYSIS AND MATHEMATICAL MODELING APPROACH -

NOVIA BUDI PARWANTO

2014

GRIPS

National Graduate Institute for Policy Studies

QUANTITATIVE STUDY ON NATURAL DISASTERS RISK MANAGEMENT POLICY

- APPLYING STATISTICAL DATA ANALYSIS AND MATHEMATICAL MODELING APPROACH -

A Dissertation

Submitted to the Faculty of the National Graduate Institute for Policy Studies

in Partial Fulfillment of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY IN SOCIAL SYSTEMS ANALYSIS

by

Novia Budi Parwanto

September, 2014

EXECUTIVE SUMMARY

The title of this dissertation is 'Quantitative Study on Natural Disasters Risk Management Policy – Applying Statistical Data Analysis and Mathematical Modeling Approach –'. This research aims to make the analysis and planning of disaster management in order to develop policies to mitigate the number of death and missing people (D&M) and/or property damages caused by natural disasters. Based on the time line of the disaster management, the analyses of the study are made in accordance with the actions taken in the three phases in disaster management, namely preparedness and mitigation, response, and recovery. In preparedness and mitigation stages, we investigate the past trend of natural disasters as well as investigate major factors to affect human casualties of natural disasters, focusing upon earthquakes and tsunamis that occurred in Japan and Indonesia. Then, we continue our investigation for measuring the damaging impacts of the 2011 Great East Japan Earthquake (GEJE) and also evaluating the recovery performance, especially on the agricultural and manufacturing sectors. Furthermore, as one of our contributions for the disaster response activities, we propose a multi commodity transshipment network flow optimization techniques under uncertainty in order to measure the robustness of the transportation network system for the emergent situation. As the case study, we apply the model to deliver relief commodities to the affected regions due to the 2009 West Sumatra earthquake.

This study was motivated by a deep sense of concern for the large number of damages or casualties in the form of loss of lives and property as a result of disasters, both natural disasters and disasters caused by human error or technological failures. This research aims to learn the "nature" of disasters in order to assist the policy makers and planners who are involved in disaster and risk policy management, particulary in the area of mitigation and preparedness, response and recovery in Japan and Indonesia. There are six objectives of this study: (i) To investigate and model the past trend of disasters with the consideration of the availability, completeness and accuracy of historical data required; (ii) To elucidate major factors to affect human casualties of natural disasters; (iii) To investigate the impact of natural disaster, i.e. the 2011 Great East Japan Earthquake (GEJE) and evaluating the restoration and reconstruction performance; (iv) To develop a multi commodity transshipment network flow optimization model under uncertainty in order to measure the robustness of the transportation network system for the emergent situation; (v) To apply the optimization model to the response action for the actual natural disaster occurred, namely the 2009 West Sumatra earthquake; and (vi) To propose policy recommendations regarding with the disaster management.

In **Chapter II**, we quantitatively investigating the past trend of natural disasters, focusing upon earthquakes and tsunamis, which occurred in Japan and Indonesia with respect to their occurrences and human casualties; including both deaths and missing people (D&M). We apply mathematical policy analysis techniques in our natural disaster risk analysis and assessment in order to develop policies to mitigate the casualties caused by these natural disasters. First, we review the historical trend of earthquakes and tsunamis related to their occurrences and D&M from 1900 to 2012 to explain their occurrence frequency and forecast the D&M using probabilistic models. We divide the entire period into three time-periods and compare their tendency in both countries. Using about 100 years of data, our study confirms that the Exponential distribution fits the data of inter-occurrence times between two consecutive earthquakes and tsunamis, while the Poisson distribution fits the data of D&M. The average numbers of inter-occurrence times of earthquakes for Japan and Indonesia are 186.23 days and

167.77 days, respectively, whilst those of tsunamis are 273.31 days and 490.71 days, respectively. We find that earthquakes with magnitudes ranging from 6.0Mw to 7.4Mw and having epicenters in the mainland cause more casualties, while those with magnitudes 7.5Mw and above and having epicenters offshore/at sea cause relatively fewer casualties. This implies that mainland earthquakes have higher probability to bring more casualties than the sea earthquakes. In terms of fatalities, earthquakes and tsunamis have caused more deaths in Japan than in Indonesia.

As a continuation of **Chapter II** which is included in the activities carried out during the first phase of disaster management, **Chapter III** highlights that the timing and magnitude of natural disasters are unpredictable, and thus are stochastic. Number of death and missing people (D&M) caused by natural disasters are often used to measure the magnitude of the disasters. By using statistical analysis, we investigate the relationship between the D&M inflicted and some parameters of natural disasters with case studies of earthquakes and tsunamis occurred in Japan and Indonesia from 1900 to 2012. The parameters under investigation are the epicenter location, earthquake magnitude, depth of hypocenter, and water height. We found that the earthquake magnitude and water height are positively affect the D&M inflicted, while the epicenter location and hypocenter depth have significant and negative effect. In addition, in Chapter III we also review the recovery process from the 2004 Aceh tsunami and the 2011 Tohoku tsunami, especially in the agriculture sector.

In **Chapter IV** we measure the damaging impacts due to the 2011 GEJE that hit Japan on March 11, 2011 and discuss about the recovery process, especially on the agricultural and manufacturing sectors. Three years have passed since the 2011 GEJE hit the northeastern part of Japan. The earthquake then triggered a devastating tsunami and a nuclear accident, which in turn created a compound disaster that claimed a large number of human casualties and devastated properties. The 2011 GEJE caused the economy growth to decline by 2.2% with the largest decrease experienced by the industrial sector (-7.1%), followed by the agricultural sector (-3.6%) and the services sector (-0.2%). The agriculture and manufacturing sectors underwent large decreases in growth since the economies of most of the affected prefectures have relied on these two sectors. Thus, by investigating the damaging impacts of the 2011 GEJE we try to evaluate the restoration and reconstruction performance in the agriculture and manufacturing sectors. Our study finds that there has been significant progress made towards restoration and reconstruction on the areas affected by the disaster. Using prefectural data from 2000 to 2012, we apply econometric methods based upon the bias-corrected least-squares dummy variable to estimate the impact of the 2011 GEJE on the agricultural and manufacturing sectors. From this analysis, two major insights emerged. First, the 2011 GEJE had a significant negative impact on agriculture and manufacturing sectors. On average, the impact on the agriculture sector was higher than on the manufacturing sector, specially, about twice as large. Second, in each sector, the impact of the disaster was perceived differently depending on the region. In both the agriculture and manufacturing sectors, the most affected prefectures experienced about triple the impact that the less affected prefectures underwent.

Based on our study in **Chapter IV**, although it cannot be denied, that there are still many people's lives greatly inconvenienced because of the damage caused, mainly in the disaster-hit areas and elsewhere in the country, but there has been significant progress made towards restoration and reconstruction on the areas affected by the disaster in the two years since. One of the important lessons learned from the recovery process due to the 2011 GEJE is that nimble handling and comprehensiveness as well as good cooperation from all parties are the keys to success in the recovery process after any major disaster, in which according to MOFA, Japan has received, so far, assistance from 163 countries and 43 international organizations.

Given a seriously emergent situation occurring e.g. just after large-scale natural disasters and so on, how to deal with victims, survivors, and damaged areas is a very critical and important problem. There are short-term and long-term responding strategies to be taken by the public sector. The former includes how to distribute necessary goods to the damaged area and transport them corresponding to their supply and demand situation as quickly as possible while the latter corresponds to trying to make long-term future plan for e.g. building new infrastructures and then making city planning. In order to obtain an optimal strategy for the former problem we try to make necessary and desirable response strategies for managing emergent cases caused by various natural disasters by solving multi commodity transshipment network flow optimization problems under various types of uncertain situations as proposed in **Chapter V**.

Still in **Chapter V**, assuming uncertainty related with each road segment's robustness, obtained from applying Monte Carlo simulation technique, and supply-demand situations with respect to various commodities, we also try to measure the robustness and importance of the transportation network system quantitatively. Our modeling approach can be applied to the actual case of the 2009 West Sumatra earthquake for making effective and efficient public policies for the emergent situations.

Finally, we are aware that the number of disasters seems to be prominent all corners of the globe which make no country or community are fully protected from the risk of disasters. Therefore, in order to avoid a large amount of human losses and unnecessary demolition of infrastructure, disaster management strategies at each phase should be well planned and improved.

LIST OF ABBREVIATION

ANCOVA	Analysis of Covariance
Bappenas	National Development Planning Board of Indonesia
BMKG	Climatology Meteorology and Geophysics Agency of Indonesia
BNPB	National Board for Disaster Management of Indonesia
BPK	The Audit Board of the Republic of Indonesia
BRR	Rehabilitation and Reconstruction Agency of Indonesia
CAO	Cabinet Office of Japan
D	Demand
D&M	Death and Missing People
EEW	Earthquake Early Warning
EM-DAT	Epidemiology of Disasters Database (The International Disaster Database)
EWS	Early Warning System
FAO	Food and Agriculture Organization of the United Nations
FDMA	Fire and Disaster Management Agency of Japan
GAP	Gross Agricultural Product
GDP	Gross Domestic Product
GEJE	Great East Japan Earthquake
GFC	Global Financial Crisis
GHTD	Global Historical Tsunami Database
Ha	Hectare
HCLP	High-Consequence Low-Probability
HHL	Health and Humanitarian Logistics
ICT	Information and Communication Technology
IIP	Index of Industrial Production
Ind	Indonesia
INFORMS	Institute for Operations Research and the Management Science
JMA	Japan Meterological Agency
Jpn	Japan
LSDVC	Bias-Corrected Least-Squares Dummy Variable
M/Mw/MMS	Moment Magnitude Scale

m^3	Cubic Meter
MAFF	Ministry of Agriculture, Forestry and Fisheries of Japan
METI	Ministry of Economy, Trade, and Industry of Japan
MIAC	Ministry of Internal Affairs and Communications
MOFA	Ministry of Foreign Affairs of Japan
MS	Management Science
NGDC	National Geophysical Data Center
NPA	National Police Agency of Japan
OR	Operations Research
PDAM	Regional Water Company
PMI	Red Cross Society of Indonesia
P-waves	First Seismic waves
RDC	Reconstruction Design Council of Japan
RED	Region with Excess Demand
RES	Region with Excess Supply
RGDP	Regional Gross Domestic Product
S	Supply
SC	Supply Center
SED	Significant Earthquake Database
SMEs	Small and Medium Enterprises
S-waves	Secondary Seismic waves
TEPCO	Tokyo Electric Power Company
UN-ESCAP	United Nations - Economics and Social Commission for Asia and the Pacific
VAM	Value Added of Manufacturing
WB	World Bank

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER IV

CHAPTER V

LIST OF FIGURES

CHAPTER I

CHAPTER II

CHAPTER III

CHAPTER IV

CHAPTER V

CHAPTER I

INTRODUCTION

1.1 Research Background

Disasters are events of huge magnitude and negative impacts on society and environment. Disaster is also defined as a crisis situation causing wide spread damage which far exceeds our ability to recover (Wassenhove, Van L.N, 2006). Disaster can hit anywhere, at any time and take any form, be it natural disasters as we have seen too often in our recent past or manmade. They affect communities and nations, causing human life losses and material damages. One classification of disasters includes the following four causes (Star, 2007) namely; by human error and technological failures, by intentional malevolence, by acts of nature, and combinations of some or all the previous. The four causes of disasters are considered, generally, low probability-high impact events, meaning, they are events with low probability of occurrence but with high impact on the community or the environment. Regarding by act of nature, the International Disaster Database EM-DAT categorized the natural disaster into 5 sub-groups, which in turn cover 12 disaster types and more than 30 sub-types (**Figure 1.1**).

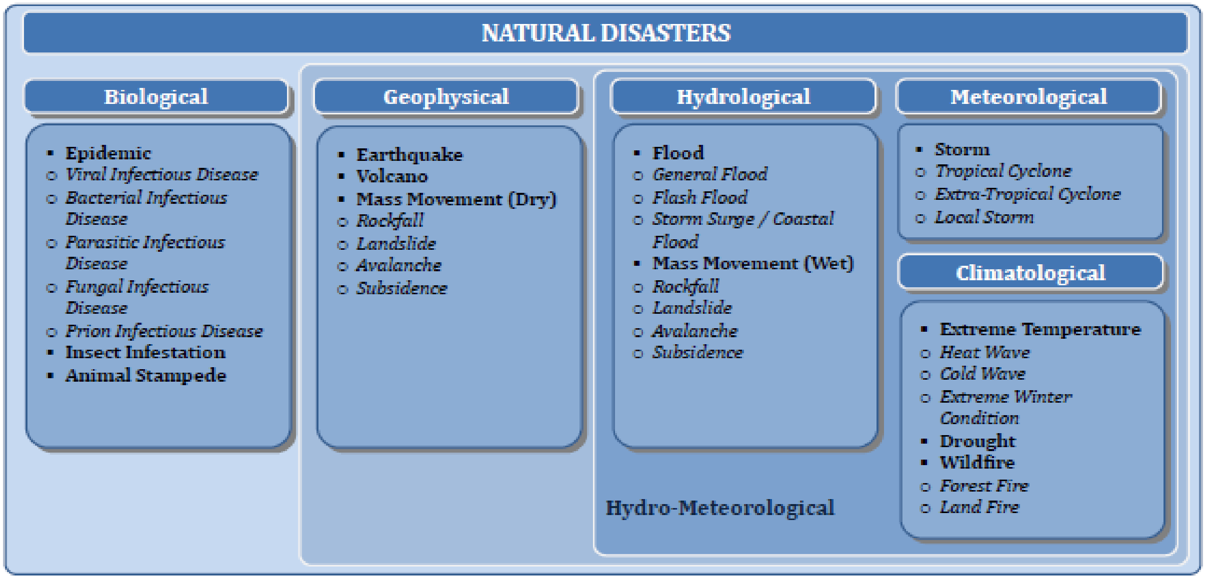


Figure 1.1 **Natural disaster classifications** (www.emdat.be)

In the last four decades, based on the International Disaster Database (EM-DAT), between 1970-1979 and 2000-2012, the number of natural disaster events reported globally increased significantly from 837 to 4,939 or increased almost six times. Over the whole period of 1970-2012, 40.8 percent of these natural disasters occurred in Asia. **Figure 1.2** portrays the increasing trend of natural disasters reported by region of continent. Such increases are allegedly associated with the increasing of population exposed to hazards.

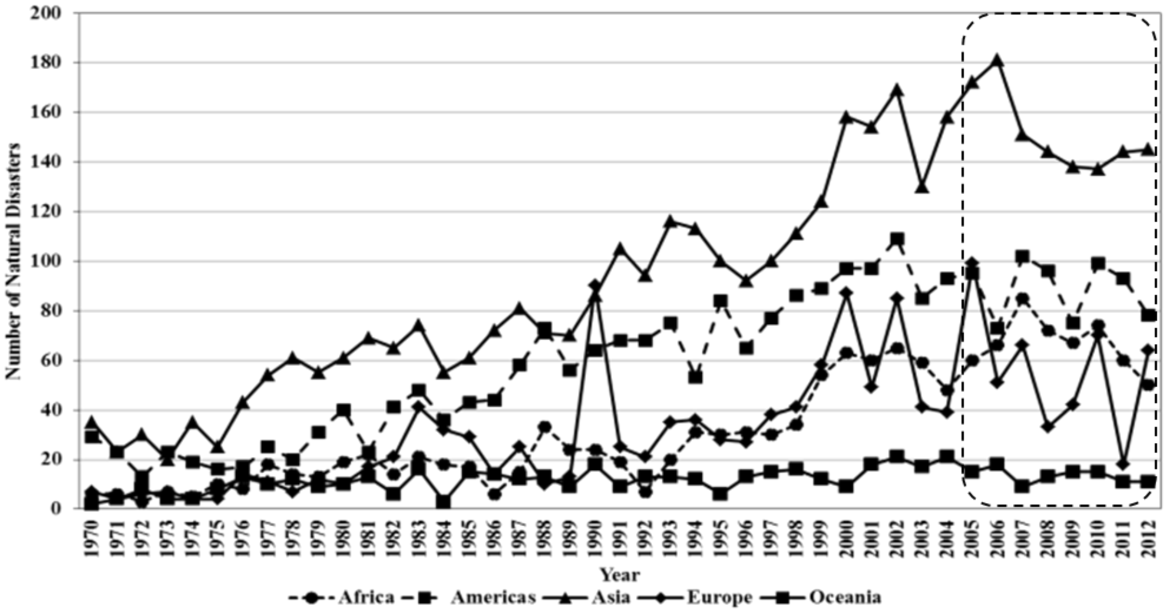


Figure 1.2 **Number of natural disaster reported, 1970-2012.**

The escalation of large-scale natural disasters in recent years such as the devastation earthquake and tsunami event in Japan and Indonesia in March 2011 and December 2004, respectively, the extreme floods in India, Germany and Switzerland in July and August 2005, the extensive bushfires due to severe droughts in Portugal and Spain in the same period, and Hurricane Katrina, which devastated the south-east coast of United States in August 2005 have caused fatalities, disruptions of livelihood, and enormous economic loss. These events show dramatically how the ongoing global environmental change and also inadequate coastal defense, lack of early warning and unsustainable practices, and even neglect can affect people all over the world. **Table 1.1** describes the natural disaster occurrences and impacts by region.

Table 1.1 **Natural disaster occurrence and impacts: regional figures**

No. of natural disasters	Africa	Americas	Asia	Europe	Oceania	Global
Climatological 2011	11	13	11	2	2	39
Avg. 2001-10	*9*	*12*	*11*	*17*	*1*	*50*
Geophysical 2011	0	5	28	1	2	36
Avg. 2001-10	*3*	*7*	*21*	*2*	*2*	*35*
Hydrological 2011	44	42	76	10	1	173
Avg. 2001-10	*44*	*39*	*82*	*24*	*6*	*195*
Meteorological 2011	9	33	31	5	6	84
Avg. 2001-10	*9*	*34*	*40*	*14*	*7*	*104*
Total 2011	64	93	146	18	11	332
Avg. 2001-10	*65*	*92*	*153*	*58*	*16*	*384*

No. of victims (millions)	Africa	Americas	Asia	Europe	Oceania	Global
Climatological 2011	20.99	2.68	40.93	0.00	0.00	64.60
Avg. 2001-10	*12.29*	*1.22*	*63.45*	*0.27*	*0.00*	*77.23*
Geophysical 2011	0.00	0.01	1.44	0.02	0.30	1.76
Avg. 2001-10	*0.08*	*1.02*	*7.77*	*0.01*	*0.04*	*8.92*
Hydrological 2011	1.44	6.94	131.37	0.02	0.00	139.77
Avg. 2001-10	*2.18*	*3.31*	*100.82*	*0.35*	*0.04*	*106.70*
Meteorological 2011	0.12	0.98	37.41	0.00	0.01	38.52
Avg. 2001-10	*0.35*	*2.72*	*35.88*	*0.11*	*0.04*	*39.10*
Total 2011	22.55	10.60	211.16	0.04	0.31	244.65
Avg. 2001-10	*14.91*	*8.27*	*207.92*	*0.74*	*0.12*	*231.95*

Damages (2011 US$ bn)	Africa	Americas	Asia	Europe	Oceania	Global
Climatological 2011	0.00	11.38	2.79	0.00	0.05	14.23
Avg. 2001-10	*0.04*	*1.90*	*3.45*	*3.23*	*0.48*	*9.10*
Geophysical 2011	0.00	0.00	212.10	0.20	18.00	230.30
Avg. 2001-10	*0.69*	*4.75*	*17.38*	*0.57*	*0.69*	*24.08*
Hydrological 2011	1.01	11.82	57.00	0.89	0.00	70.72
Avg. 2001-10	*0.28*	*3.15*	*11.15*	*5.57*	*1.24*	*21.39*
Meteorological 2011	0.01	44.12	4.14	0.10	2.50	50.87
Avg. 2001-10	*0.08*	*40.47*	*9.62*	*4.03*	*0.56*	*54.77*
Total 2011	1.02	67.32	276.03	1.19	20.56	366.12
Avg. 2001-10	*1.10*	*50.27*	*41.61*	*13.40*	*2.97*	*109.35*

Source: Annual Disaster Statistical Review 2011: The numbers and trends

Japan and Indonesia are no exception, where both countries are geographically located on the Ring of Fire which causes these two countries vulnerable to disasters. Japan lies at the confluence of four plates, which are the Eurasian plate and North American plate in the north, the Pacific plate in the east and Philippines sea micro plate in the south. On the other hand, Indonesia lies at the confluence of three plates, namely

Indo-Australia plate in the south, Euro-Asia plate in the north, and Pacific plate in the east. Subduction between these plates, such as the Pacific plate and the Eurasian plate in Japan and the Indo-Australian and Euro-Asian plate in Indonesia, causing earthquakes and series lines of active volcanoes along the islands of Japan and Indonesia. This led to Japan and Indonesia prone to natural disasters such as earthquakes, volcanoes, and tsunamis. These kind of natural disasters caused numbers of casualties and/or severe property damages.

As it has been a common awareness that, nowadays, disasters seem to be prominent at all corners of the globe. No country nor community could claim themselves completely protected from the risk of disasters. Thus, the importance of disaster management is undeniable, since a large amount of human losses and unnecessary demolition of infrastructure can be avoided with very responsive Disaster Management Action. The Georgia Tech Health & Humanitarian Logistics Center (HHL) divides the disaster timeline into three phases, namely Pre-disaster, Disaster, and Post-disaster. **Figure 1.3** depicts the disaster timeline along with the activities or actions taken in the disaster management.

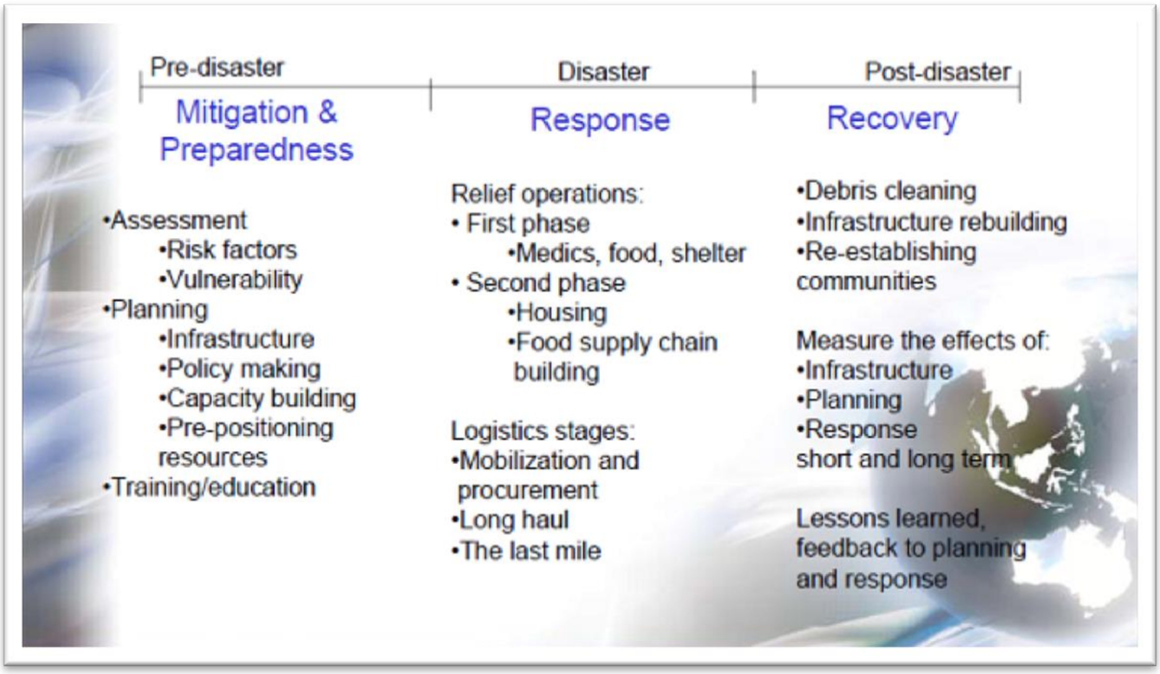


Figure 1.3 **Three phases in the disaster management.**

Mitigation is the application of measures that will either prevent the onset of a disaster or reduce the impacts should one occur; it aims to minimize the effects of disasters. Preparedness activities prepare the community to respond when a disaster occurs. Response is the employment of resources and emergency procedures as guided by plans to preserve life, property, the environment, and the social, economic, and political structure of the community; it aims to minimize the hazards created by a disaster. Finally, Recovery involves the actions taken in the long term after the immediate impact of the disaster has passed to stabilize the community (*Rehabilitation*) and to restore some semblance of normalcy (*Reconstruction*).

Natural hazards events cannot be prevented from occurring, but their impacts on people and property can be reduced if advance action is taken to mitigate risks and minimize vulnerability to natural disasters. This implies the need for effective methods or techniques to minimize casualties and costs incurred due to disasters.

Therefore, based on three phases of disaster management, the research will attempt to make a contribution to each phase of the activity. First of all, for the mitigation and preparedness phases which carried on in the pre-disaster, we sought to investigate the past trend of natural disasters, focusing upon earthquakes and tsunamis that occurred in Japan and Indonesia. We also investigate major factors to affect human casualties of natural disasters by using the same data of earthquakes and tsunamis that occurred in Japan and Indonesia. In both of the studies at this first phase, we apply mathematical policy analysis techniques in our natural disaster risk analysis and assessment in order to develop policies to mitigate the casualties caused by natural disasters. Then, we also investigate the damaging impacts of the 2011 Great East Japan Earthquake (GEJE) as well as evaluating the restoration and reconstruction performance, especially on the agricultural and manufacturing sectors. In addition, one of the activities conducted in the response phase, namely delivering relief commodities, an activity that would be conducted just after the disaster occurred, also have been studied in this research. In which, we will propose a multi commodity transshipment network flow optimization models in order to carry out humanitarian logistics or logistics in emergency relief.

1.2 Research Problems and Objectives

This study was motivated by a deep sense of concern for the large number of damages or casualties in the form of loss of lives and property as a result of disasters, both natural disasters and disasters caused by human error or technological failures. This research aims to learn the “nature” of disasters in order to assist the policy makers and planners who are involved in disaster and risk policy management, especially in the area of mitigation, preparedness, response, and recovery in Japan and Indonesia, by applying statistical data analysis and mathematical modeling approach.

Our methodologies will fall into the methodologies of Operations Research/Management Science (OR/MS) range. Though there is no 'official definition' of OR, Altay and Green (2006) concluded that the definitions of OR converged to 'scientific approach to aid decision making in complex systems’. INFORMS[1] also stated that operations researchers draw upon analytical techniques including mainly simulation, optimization, and probability and statistics.

There are six objectives of this study:

1. To investigate and model the past trend of disasters with the consideration of the availability, completeness and accuracy of historical data required.
2. To elucidate major factors to affect human casualties of natural disasters.

[1] INFORMS stands for the Institute for Operations Research and the Management Sciences, which is the largest society in the world for professionals in the field of operations research (O.R.), management science, and analytics (www.informs.org).

3. To investigate the impact of natural disaster, i.e. the 2011 Great East Japan Earthquake and evaluating the restoration and reconstruction performance.
4. To develop a multi-commodity transshipment network flow optimization model under uncertainty in order to measure the robustness of the transportation network system for the emergent situation.
5. To apply the optimization model to the response action for the actual natural disaster occurred, namely the 2009 West Sumatra earthquake.
6. To propose policy recommendations related with the disaster management.

1.3 Research Framework – Data and Past Research

No country or community could claim that they are fully protected from the risk of natural disasters. The ability of communities and countries to efficiently and effectively protect their populations and infrastructure, namely in reducing human casualties and property loss as well as to rapidly recover; could be tested by the occurrence of natural disasters.

As natural disasters are large intractable problems, therefore, a community and a country that have a strong resilience in dealing to natural disasters sought to be realized by each government. The measures relating to the preparation, mitigation, response, and recovery should be well planned and integrated by each decision maker.

Given the large number of casualties and damage and/or loss inflicted by natural disasters as **in Table 1.1**, many studies have been done related to various types of natural disasters (as in **Figure 1.1**.) and the disaster timeline (as in **Figure 1.3**). **Table 1.2** lists the past studies in disaster management according to the type of natural disasters and the lifecycle stage using OR technique (Altay and Green, 2006).

Based on the natural disaster classification by EM-DAT, this study, thus, will only cover geophysical, particularly earthquake and tsunami. One of the reasons is because these types of disasters have caused huge losses to people and their property and cause severe damage to the environment and life. In addition, as previously explained, that Japan and Indonesia are prone to these types of natural disasters.

Table 1.2 **Past studies in disaster management by type of natural disaster and stage**

Type of natural disaster	**Stage of disaster management**			
	Mitigation	**Preparedness**	**Response**	**Recovery**
No Specified natural disaster type	Atencia and Moreno (2004), Current and O'Kelly (1992), Drezner (1987), Dudin and Semenova (2004), Economou (2004), Economou and Fakinos (2003), Englehardt (2002), Frohwein et al. (1999), Frohwein and Lambert (2000), Frohwein et al. (2000), Gillespie et al. (2004), Haimes and Jiang (2001), Hsieh (2004), Lee (2001), Mehrez and Gafni (1990), Perry and Stadje (2001), Peterson (2002), Rudolph and Repenning (2002), Semenova (2004), Shin (2004), Yi and Bier (1998)	Batta and Mannur (1990), Daganzo (1995), Dudin and Nishimura (1999), Gregory and Midgley (2000), Obradovic and Kordic (1986), Pidd et al. (1996), Reer (1994), Takamura and Tone (2003), Yamada (1996)	Barbarosoglu et al. (2002), Belardo et al. (1984a,b), Brown and Vassiliou (1993), de Silva and Eglese (2000), Haghani and Oh (1996), Hamacher and Tufekci (1987), Mendonca et al. (2000), Oh and Haghani (1997), Sarker et al. (1996), Swartz and Johnson (2004), Zografos et al. (1998)	Bryson et al. (2002), Freeman and Pflug (2003), Guthrie and Manivannan (1992), Manivannan and Guthrie (1994), Nikolopoulos and Tzanetis (2003)
Asteroid	Kent (2004)	-	-	-
Earthquake	Dong et al. (1987), Peizhuang et al. (1986), Tamura et al. (2000)	Viswanath and Peeta (2003)	Barbarosoglu and Arda (2004), Fiedrich et al. (2000), Ozdamar et al. (2004)	Chang and Nojima (2001), Cret et al. (1993), Song et al. (1996)
Flood	Coles and Pericchi (2003), Esogbue (1996), Esogbue et al. (1992), Lian and Yen (2003), Suzuki et al. (1984)	Hernandez and Serrano (2001), Wei et al. (2002)	Shim et al. (2002)	
Hurricane	Davidson et al. (2003)	Sherali et al. (1991)		Boswell et al. (1999), Lambert and Patterson (2002)
Volcanic eruption	Leung et al. (2003)	-	-	-
Wildfire	Simard and Eenigenburg (1990)	-	-	-

The data that we used in this research stems from various sources. For investigating the earthquakes and tsunamis disasters, we mainly used data from the Significant Earthquake Database (SED) and the Global Historical Tsunami Database (GHTD). To complement these two databases, we also utilize data from the

International Disaster Database EM-DAT, the Japan Meteorological Agency (JMA), and the Indonesian Climatology Meteorology and Geophysics Agency (BMKG). While for measuring the impact of the 2011 Great East Japan Earthquake and evaluating the recovery performance, we make use of data from the Cabinet Office of Japan, Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF), Ministry of Economy, Trade, and Industry of Japan (METI), and Prefectural Governments. Finally, for the application of the transshipment network flow optimization methods we use data from the Indonesian National Board for Disaster Management (BNPB), Indonesian Red Cross Society (PMI), Indonesian National Police, and Government of West Sumatra.

In line with the objectives of the research; this study will serve as a basic research on disasters and risk policy management in the field of mitigation and preparedness, response, and recovery. The general research framework of this study is depicted in **Figure 1.4**. The case of Japan and Indonesia will be taken into consideration for the purpose of model validation, justification, and policy evaluation.

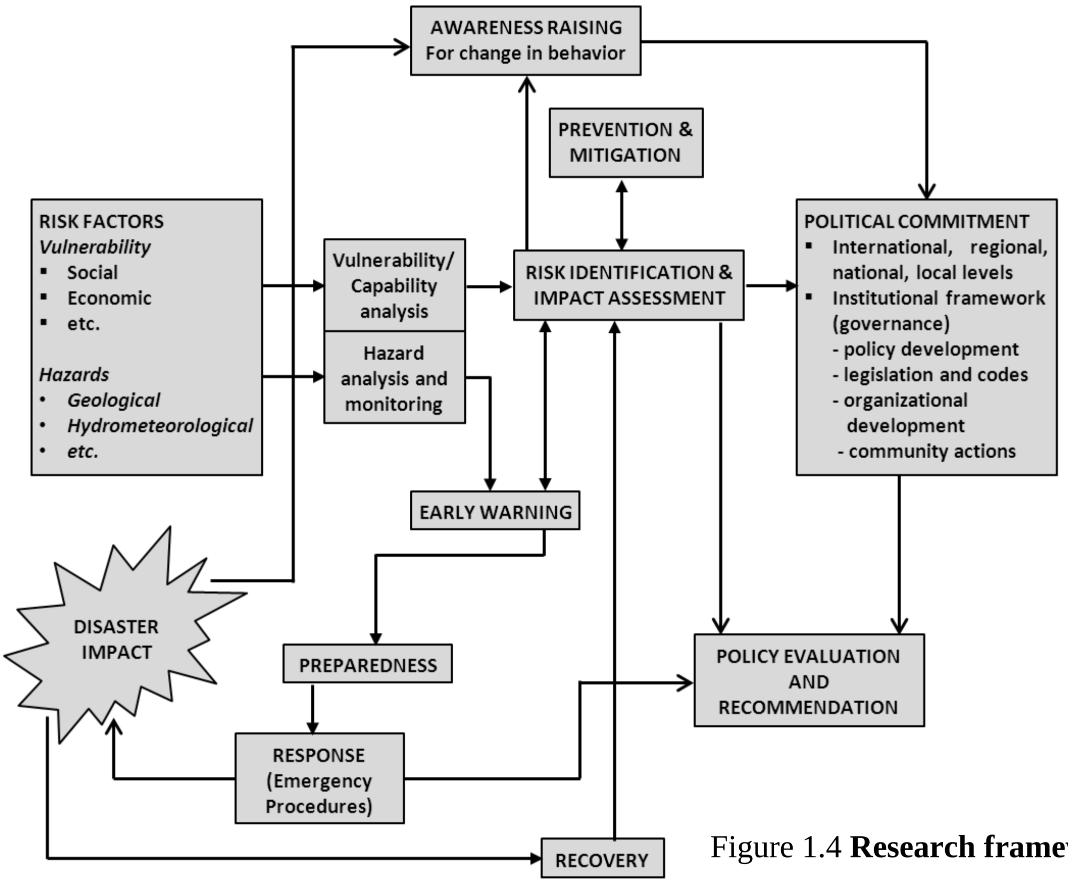


Figure 1.4 **Research framework.**

CHAPTER II

INVESTIGATING EARTHQUAKE AND TSUNAMI DISASTERS IN JAPAN AND INDONESIA

As one of the activities in the first phase of disaster management, which is aimed to assess and analyze the natural disaster risk, a mathematical modeling approach is used to analyze the natural disasters, of earthquakes and tsunamis in Japan and Indonesia from 1900 to 2012.

2.1 Natural Disasters in Japan and Indonesia

This section will briefly describe the natural disasters that occurred in Japan and Indonesia during the period 1900-2012. Historical data from the International Disaster Database (EM-DAT) will be used to present the number of death and missing people (D&M) and natural disasters from 1900 to 2012. For a disaster to be included in the EM-DAT database at least one of the following criteria must be fulfilled: Ten or more people are reported killed, one hundred or more are reported affected. A state emergency is declared, and a call is made for international assistance.

Japan and Indonesia are two archipelago countries with populations over 100 million people. Both of them are also located along the Pacific Ring of Fire, which makes them particularly prone to natural disasters. Throughout their history, Japan and Indonesia have encountered extensive devastation as a consequence of a variety of natural disasters including both geophysical disasters such as earthquakes, tsunamis, landslides, volcanic eruptions, and hydro meteorological disasters such as typhoons, rainstorms, floods, heavy snow, droughts, strong winds, and heat waves (Oyama et al., 2011). Among these natural disasters, some commonly occur in both Japan and Indonesia, namely earthquakes, tsunamis, and volcanic eruptions.

Natural disasters in relation to exposure and vulnerability all have corresponding economic costs and social costs (Hallegate, 2010); indeed, "if there were no costs they would not be classified as disasters in the first place" (Dore, 2003). The economic impact of a disaster usually consists of direct (e.g. damage to infrastructure, crops, housing) and indirect (e.g. loss of revenue, unemployment, market destabilization) costs to the local economy. Given the damage and costs that natural disasters can bring, it is important to understand the "nature" of disasters in order to assist policy makers and planners who are involved in disaster preparedness and mitigation.

Since Japan and Indonesia have a long history of experiencing natural disasters and the lessons learned from each disaster are usually documented by various agencies, non-government organizations and academic reports. Analyzing historical data can assist in identifying the main vulnerabilities and priority areas in relation to natural disasters such as earthquakes and tsunamis. Gusiakov et al. (2007) estimate that about 700,000 fatalities resulted from tsunamis during the last 250 years from 1755 to 2005. Hence, we believe that investigating the frequency and intensity of recent tsunamis is important (Dunbar, 2012). Moreover, according to Suppasri A, et al. (2012), Japan faces the highest tsunami risk, followed by Indonesia. The most recent tsunami events, which claimed many lives and caused severe damages, are the 2011 Great East Japan tsunami and the 2004 Indian Ocean tsunami. A comparison of these tsunamis is presented in **Table 2.1**. Powerful earthquakes with magnitudes of class 9.0Mw[3] triggered both of these tsunamis. Significant differences between these two tsunamis include the number of fatalities, where the 2004 Indian Ocean tsunami caused deaths about ten times greater than that of the 2011 Great East Japan tsunami, and the number of countries affected.

[3] The primary magnitudes of earthquakes used in this paper, as taken from the Significant Earthquake Database (SED) and the Global Historical Tsunami Database (GHTD) issued by the National Geophysical Data Center (NGDC), are measured in Moment Magnitude Scale, abbreviated as MMS and denoted as Mw or M.

Table 2.1 **Comparison between the 2004 Indian Ocean tsunami and the 2011 Great East Japan tsunami**

Item	2004 tsunami	2011 tsunami
Earthquake magnitude	9.3	9
Size of rupture (km^2)	1,000 * 150	500 * 200
Max. tsunami height (m)	50.9	40.5
No. of deaths	230,000	20,000
No. of affected countries	15	Mostly in Japan

Earthquakes are the most destructive natural hazard, and one of the most destructive earthquakes in Japan was the Great Kanto earthquake that occurred in 1923. Earthquakes take place because of the sudden transient motion of the ground as a result of elastic energy. Earthquakes not only destroy villages and cities and result in many deaths, but subsequently may also cause destabilization of the economic and social structure of the nation (Hallegate, 2010, Dore, 2000, and Nanto, 2011). Earthquakes can also trigger other natural disasters such as tsunamis, landslides, and volcanic eruptions.

Figure 2.1 presents the number of natural disasters and D&M from 1900 to 2012 in Japan. Here, the highest number of D&M is 148,344, which occurred in 1923, a year that had “only” four recorded natural disasters (two earthquakes, a landslide and a storm). One of these disasters is known as the 1923 Great Kanto earthquake, which caused about 99,331 deaths. Because the earthquake struck at lunch time (11:58 am) when many people were cooking with fire, many people died as a result of the many large fires that broke out. Some fires developed into firestorms that swept across cities. The second largest number of D&M is 25,136, which occurred in 2011, the year in which the most destructive tsunami in Japan occurred, namely, the 2011 Great East Japan tsunami, which occurred at 14:46 pm on March 11th, 2011 and caused about 19,057 deaths. In addition, regarding the tsunamis in Japan, besides the 2011 Great East

Japan tsunami, Japan has experienced other large tsunamis, namely the 1933 Showa-Sanriku, which occurred on March 2nd, 1933 at 02:31 am and the 1896 Meiji tsunami, which occurred on June 15th, 1896 at 19:32 pm. The 1933 Showa and 1896 Meiji tsunamis had epicenters located off the coast of Sanriku of the Tohoku region of Honshu and were generated by 8.4Mw and 8.5Mw earthquakes and attained a height of approximately 28 and 25 meters resulting in nearly 3,000 and 22,000 deaths, respectively. The third largest number of D&M is 6,158, which occurred in 1945. The natural disasters and estimated fatalities in 1945 are an earthquake in Mikawa (1,961 deaths), the Akune storm (451 deaths) and the Makurazaki storm (3,746 deaths).

Figure 2.2 shows the number of natural disasters and D&M in Indonesia during the period of 1900 to 2012. In **Figure 2.2**, the highest number of D&M is 173,657 people, which happened in 2004, a year that had 18 recorded natural disasters. One of these 18 natural disasters was one of the greatest recorded tsunamis in history, that is the 2004 Indian Ocean earthquake and tsunami, which occurred on December 26th, 2004 at 07:58 am. This disaster itself claimed as many as 172,761 lives in Indonesia alone. The second highest number of D&M caused by natural disasters occurred in 1966, during which about 9,264 people lost their lives. The natural disaster events and estimated fatalities in 1966 are as follows: a drought in Lombok (8,000 deaths), a flood in Java (176 deaths), a volcanic eruption in Mount Kelud (1,000 deaths) and a volcanic eruption in Mount Awu (88 deaths). In third place are natural disasters that happened in 2006, which claimed about 7,421 lives. In 2006, there were 18 recorded natural disasters, of which two of them are the 6.3Mw earthquake in Yogyakarta which occurred on May 27th, 2006 at 05:55 am and caused about 5,757 deaths and the Tasikmalaya tsunami, triggered by a 7.7Mw earthquake, that happened on July 17th, 2006 and killed about 802 people.

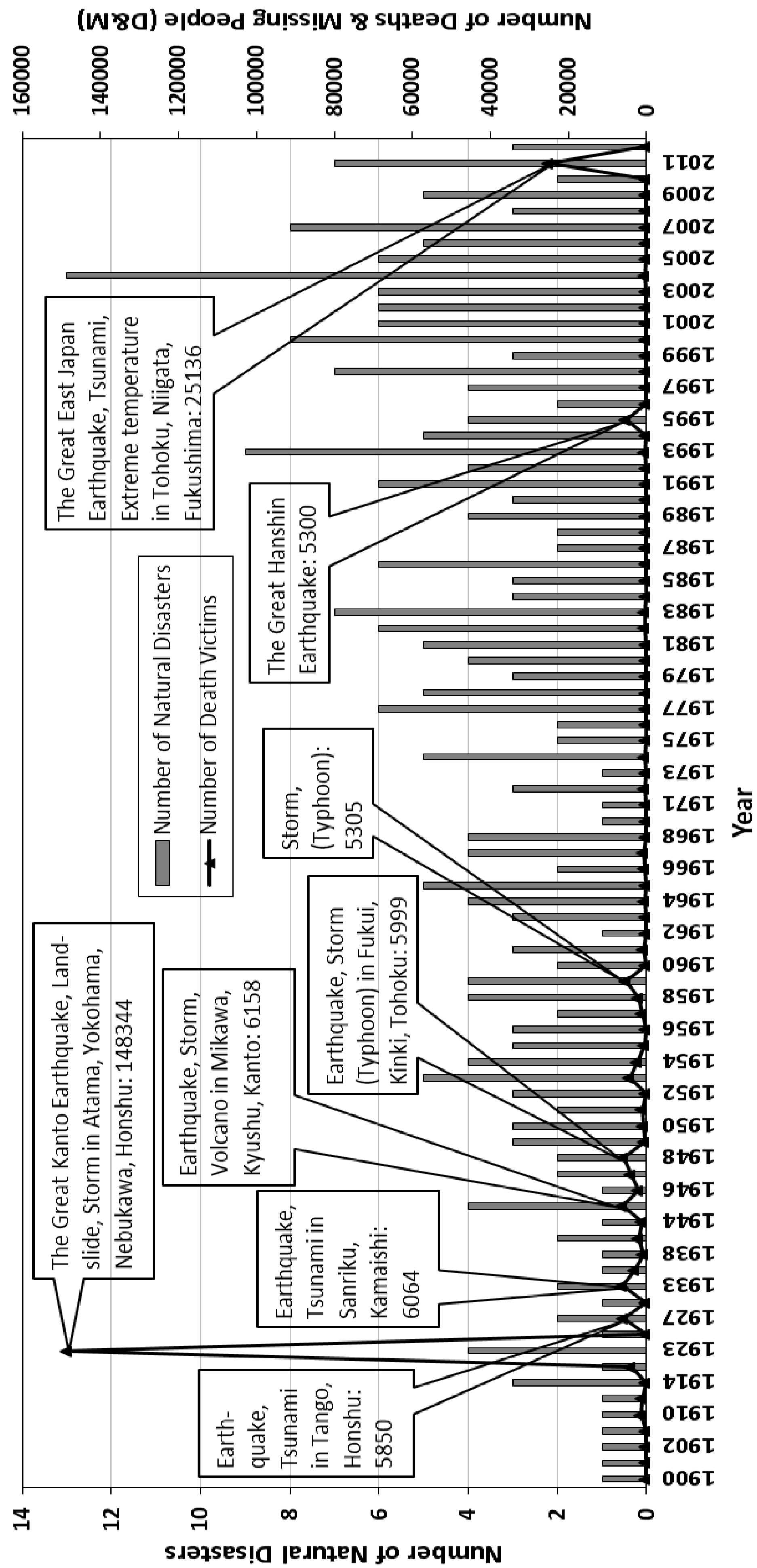


Figure 2.1 **Number of natural disasters and number of depths and missing people in Japan from 1900 to 2012.**

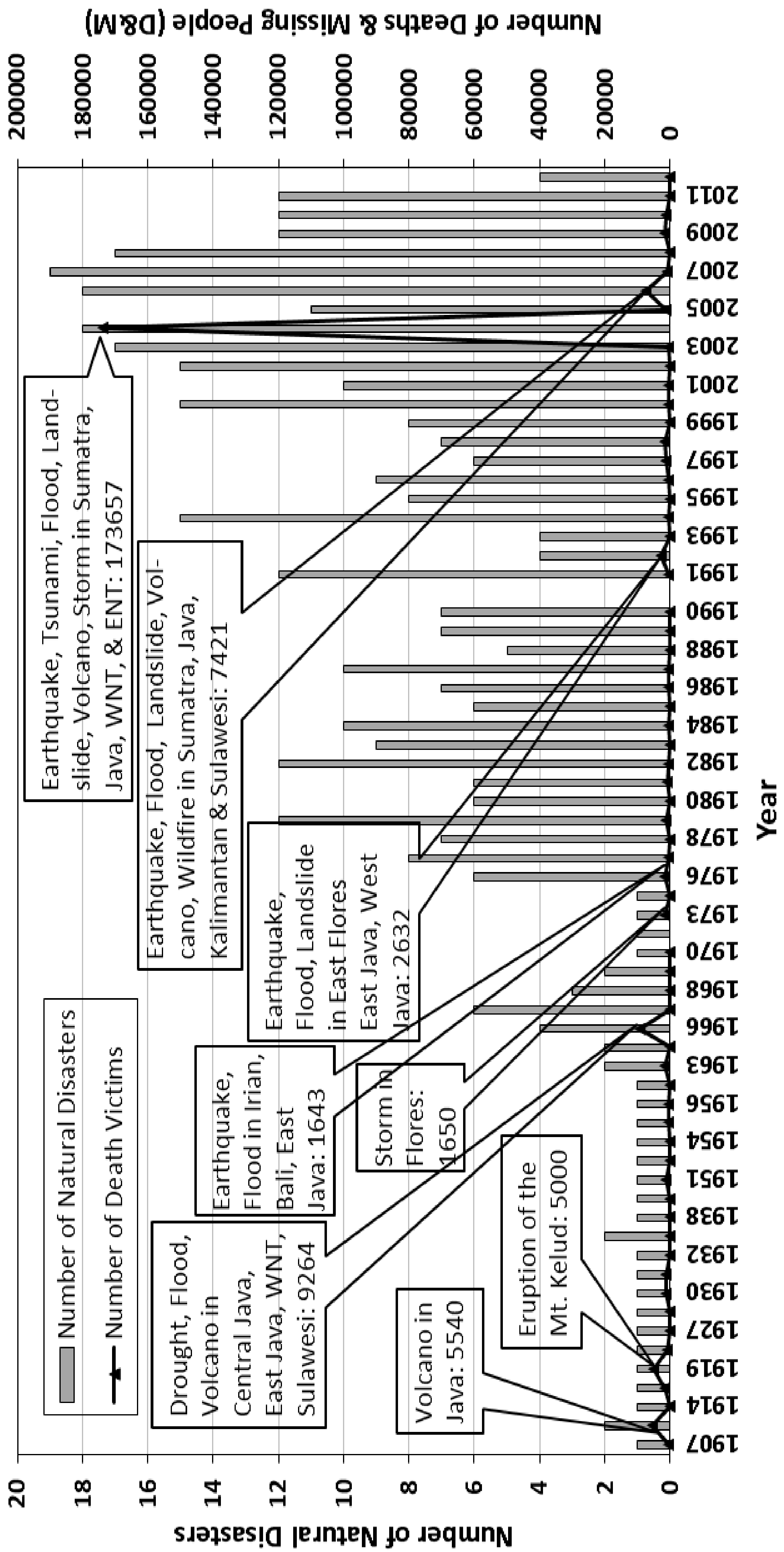


Figure 2.2 **Number of natural disasters and number of depths and missing people in Indonesia from 1900 to 2012.**

Figure 2.3 presents the share of the number of natural disasters in Japan and Indonesia from 1900 to 2012. According to EM-DAT, the total number of natural disasters during the period in Japan is 294, while that in Indonesia is 416. In Japan, storms or typhoons, with 144 occurrences, have the highest share at 49%, followed by earthquakes with 57 occurrences (19%). In Indonesia, floods have the highest share at 35% with 145 occurrences, followed by earthquakes with 109 occurrences (26%). Hence, earthquakes (including subsequent tsunamis) are the second most frequent natural disaster in both countries.

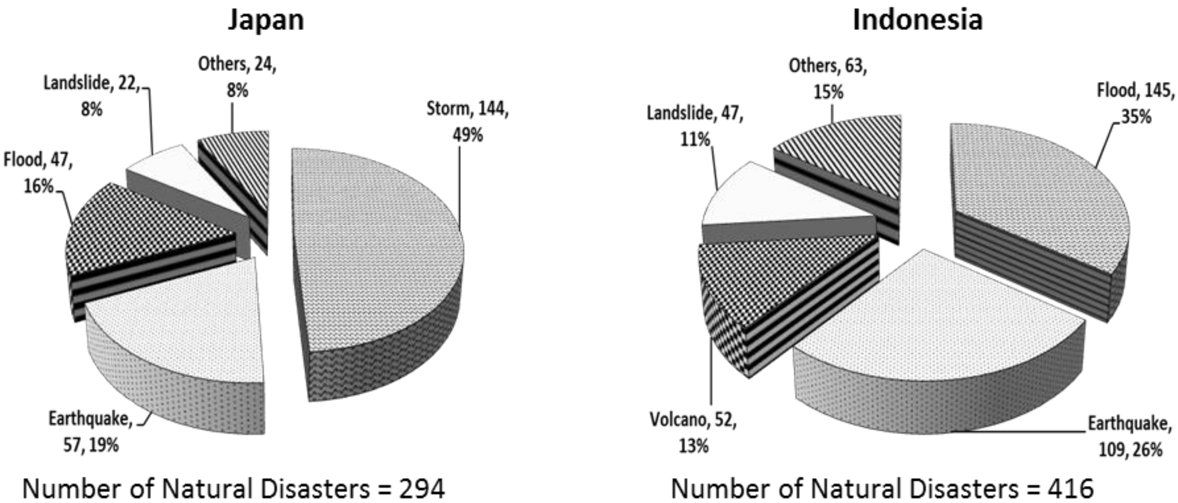


Figure 2.3 **Share of the natural disasters in Japan and Indonesia, 1900-2012.**

2.2 Data Analyses on Earthquakes and Tsunamis

As **Figure 2.3** indicates that earthquakes commonly occur in Japan and Indonesia. The earthquakes that occur sometimes and unexpectedly are followed by other natural disasters such as tsunamis, landslides, eruptions, and so on. Among these, as has been recorded by the NGDC[4], tsunamis are one of the most deadly natural

[4] The National Geophysical Data Center (NGDC), located in Boulder, Colorado, is a part of the US Department of Commerce (USDOC), National Oceanic & Atmospheric Administration (NOAA). The NOAA/WDC tsunami database is a listing of historical tsunami source events and run-up locations throughout the world that range in date from 2000 B.C. to the present. The definition used in this database is the arrival or travel time of the first wave that arrives at a run-up location. The first wave may not have been the largest wave; therefore the travel time reported in the original source may have been the second

disasters causing not only substantial damage and loss, but also a significant number of death and missing people (D&M).

This study uses the database of all the major earthquakes and tsunamis from NGDC for Japan and Indonesia from 1900 to 2012[5] (note: for 2012, the data cover only up to mid-2012, due to the availability of the existing database when this study was conducted). Regarding earthquake measurement, E. Wiechert of Göttingen, a German seismologist, introduced a seismograph with a viscously-damped pendulum as a sensor. He then modified his first seismograph into a mechanically-recording seismograph using an inverted pendulum. Thus, the seismograph was completed in 1900. Furthermore, in the early 1900s, B.B. Galitzin, a Russian seismologist, developed the first electromagnetic seismograph, which has proven to be much more accurate and reliable than previous mechanical instruments. Incidentally, all modern seismographs are electromagnetic. Thus, we consider the year 1900 as the beginning of the modern era of earthquake monitoring. In addition, the data available at EM-DAT also started from 1900. Thus we decided to collect the data of earthquakes and tsunamis during the period from 1900 to 2012. The source of earthquake data is the Significant Earthquake Database (SED), issued by NGDC, which contains information on destructive earthquakes from 2150 B.C. to the present that meet at least one of the following criteria: Moderate damage (approximately $1 million or more), 10 or more deaths, Magnitude 7.5Mw or greater, Modified Mercalli Intensity X or greater, or tsunami

---

or third wave. The events were gathered from scientific and scholarly sources, regional and worldwide catalogs, tide gauge reports, individual event reports, and unpublished works. There are currently over 2,000 source events in the database with event validities > 0 (0 = erroneous entry). In this database, the validity of the actual tsunami occurrence is indicated by a numerical rating of the reports of that event: -1 = erroneous entry, 0 = event that only caused a seiche or disturbance in an inland/a mainland river, 1 = very doubtful tsunami (certainty of tsunami occurrence is 25%), 2 = questionable tsunami (certainty of tsunami occurrence is 50%), 3 = probable tsunami (certainty of tsunami occurrence is 75%), and 4 = definite tsunami (certainty of tsunami occurrence is 100%). In this study, we only include tsunami events in which have the certainty of a tsunami occurrence is above 50% (validity ≥ 2).

[5] The difference in the number of earthquakes and tsunamis of the EM-DAT and NGDC is due to differences in concepts and definitions and methodologies used in the collection of data by these two institutions.

generated. SED contains information about the date and location of earthquake, earthquake parameters: moment magnitude scale (Mw) and focal depth (km), and earthquake effects: D&M and damage.

The source of the tsunami data is the Global Historical Tsunami Database (GHTD), also issued by NGDC. This database consists of two related files containing information on tsunami events from 2000 B.C. to the present in the Atlantic, Indian, and Pacific Oceans; and the Mediterranean and Caribbean Seas. Although both databases are issued by NGDC, they have separated the consequences or effects of both disasters, such as fatalities, injuries, financial losses, destroyed and damaged houses. Therefore, in this study we are able to study the effects of earthquakes and tsunamis separately.

According to the NGDC database, there were 221 significant earthquakes[6] from 1900 to 2012 in Japan. During this period, the earthquake that claimed the greatest number of D&M was the 1923 Great Kanto earthquake, followed by earthquakes that occurred in 1995, 1948 and 1927. The SED also reveals that almost all the major earthquakes, namely more than two-thirds, and a huge loss of life occurred on Honshu Island. For providing an overall picture only, **Figure 2.4** shows earthquakes that caused D&M of more than 1,000 people by year (exclude the 1923 Great Kanto earthquake).

In Indonesia, there were 246 significant earthquakes from 1900 to 2012. The earthquake that caused the most deaths occurred in 2006 with 5,757 people, followed by earthquakes that occurred in 1917, 2005 and 2009. For an overall picture, **Figure 2.5** depicts the earthquakes that caused D&M of more than 1,000 lives by year. The majority of large earthquakes struck on the islands of Sumatra, Java and Bali, Sulawesi and Irian Jaya, the four largest islands in Indonesia, leaving Kalimantan Island as the largest island not threatened, since it does not lie on the path of the Ring of Fire.

[6] The definition of significant earthquake follows the criteria established by the NGDC.

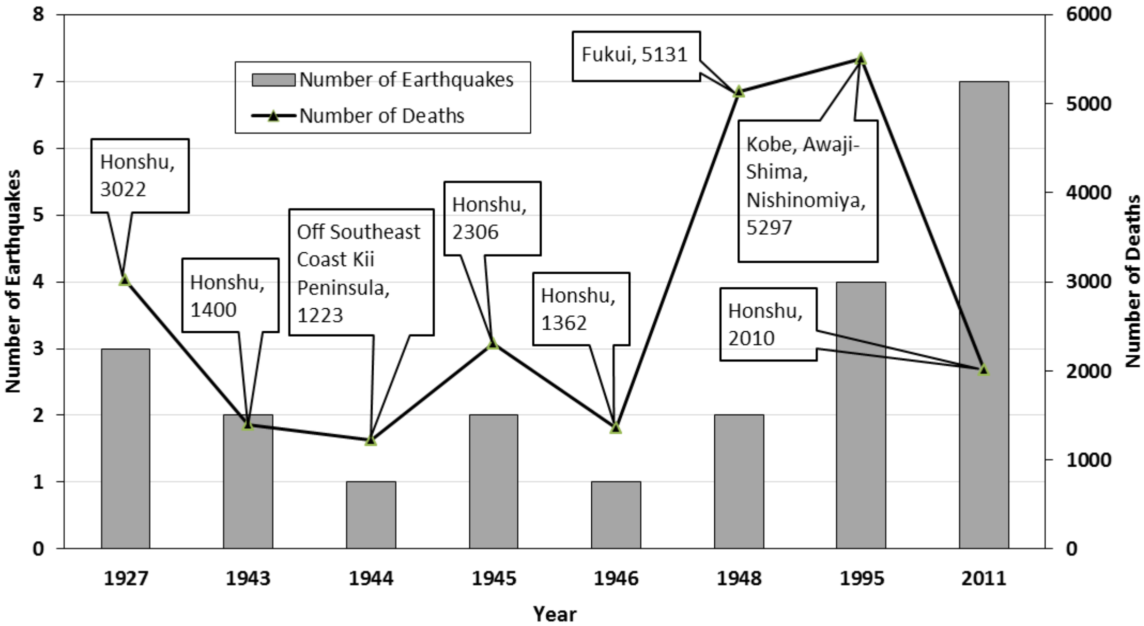


Figure 2.4 **Earthquakes that caused more than 1,000 deaths by year in Japan.**

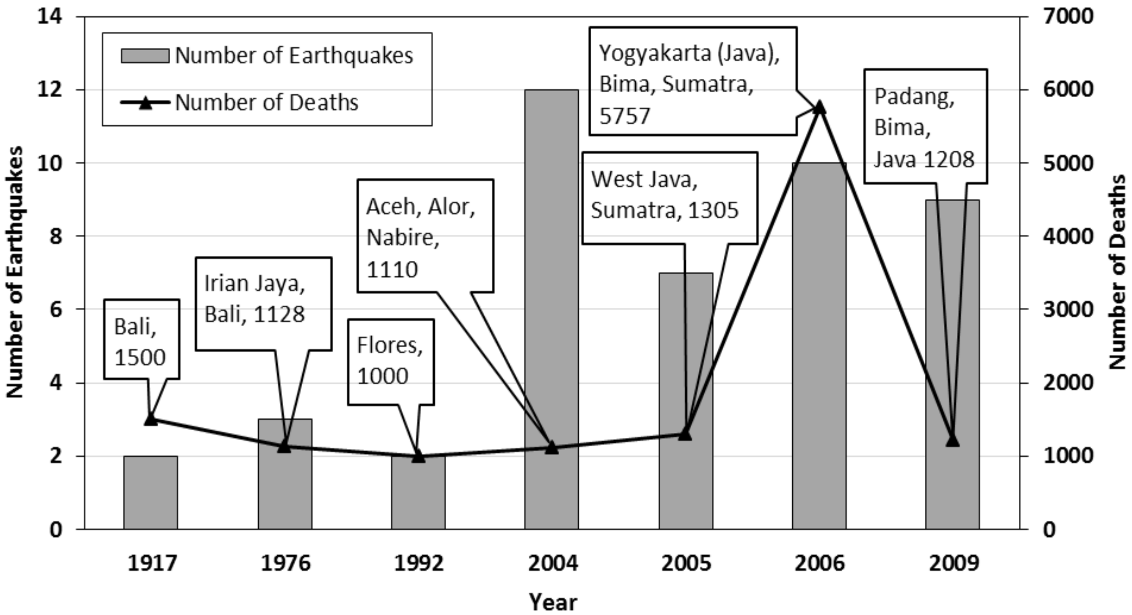


Figure 2.5 **Earthquakes that caused more than 1,000 deaths by year in Indonesia.**

From 1900 to 2012, 149 tsunamis occurred in Japan. Of these tsunamis, 20 tsunamis claimed a substantial number of victims, namely tsunamis that occurred in Sagami bay, Sanriku, off the southeast coast of the Kii Peninsula, off the south coast of Honshu, and off the Pacific coast of Tohoku where the 2011 Great East Japan tsunami took place. **Figure 2.6** shows the tsunamis that caused more than 100 deaths by year (exclude the 2011 Great East Japan tsunami).

In Indonesia beside the 2004 Indian Ocean tsunami, which had its epicenter off the west coast of Aceh, there were 84 tsunamis during 1900-2012. They include tsunamis in Lomblen Island, Flores and off the coast of West Java. **Figure 2.7** shows the tsunamis that caused more than 100 deaths by year (exclude the 2004 Indian Ocean tsunami).

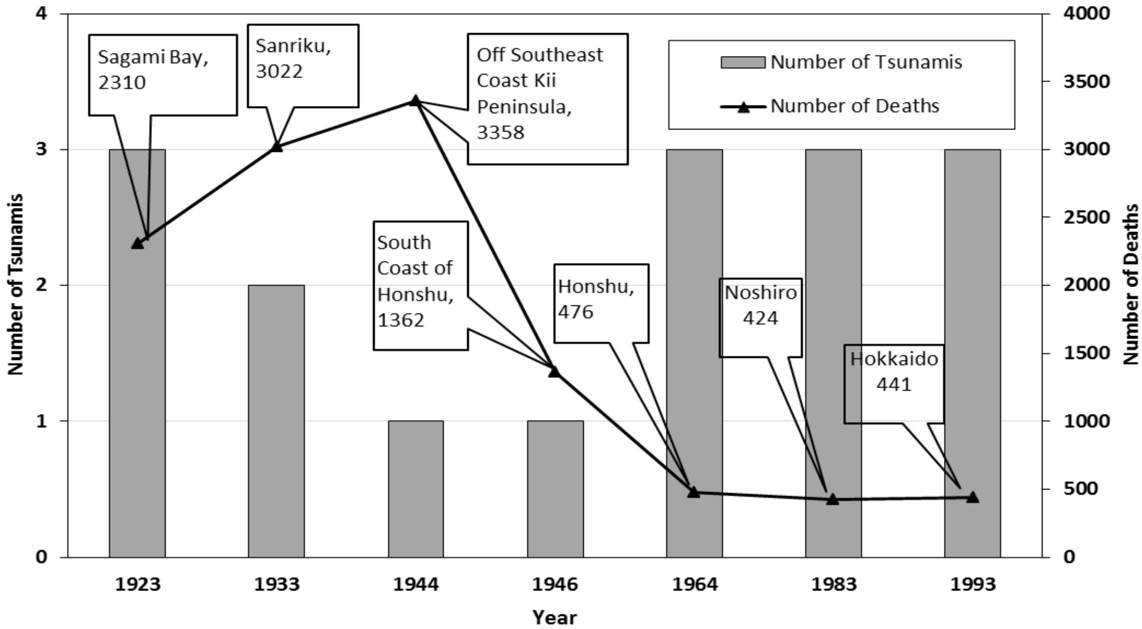


Figure 2.6 **Tsunamis that caused more than 100 deaths by year in Japan.**

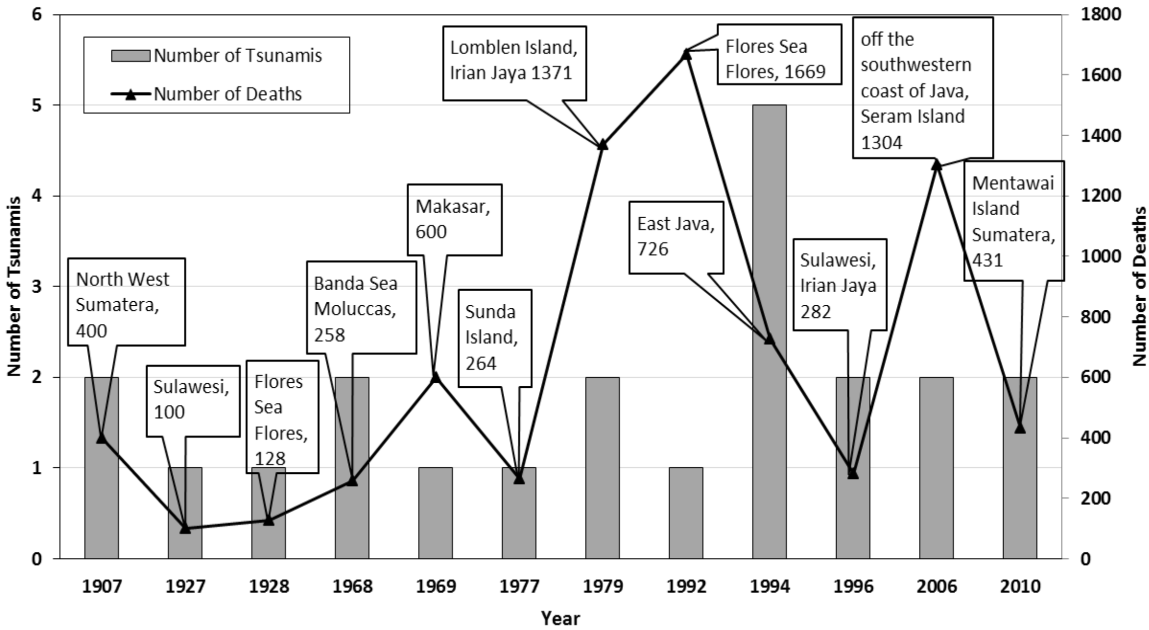


Figure 2.7 **Tsunamis that caused more than 100 deaths by year in Indonesia.**

Figure 2.8 shows the share of the causes of tsunami events in Japan and Indonesia during the period 1900-2012. We find that most of the tsunamis are caused by earthquakes alone, 95% and 88%, respectively, in Japan and in Indonesia. As an earthquake with a certain level of magnitude can trigger a tsunami, it is necessary for the existence of an early warning system (EWS) against the possibility of a tsunami. Moreover, as pointed out by Oki and Nakayachi (2012), conveying basic knowledge of a hazard is also very important; in other words, to enhance the effectiveness of the EWS, a good under-standing and improved public appraisal of tsunamis are important. From **Figure 2.3** and **Figure 2.8**, we see that earthquakes are common in Japan and Indonesia, and earthquakes are the main trigger of most tsunamis. The question is whether there are similar patterns between these two natural disasters in Japan and Indonesia from 1900 to 2012.

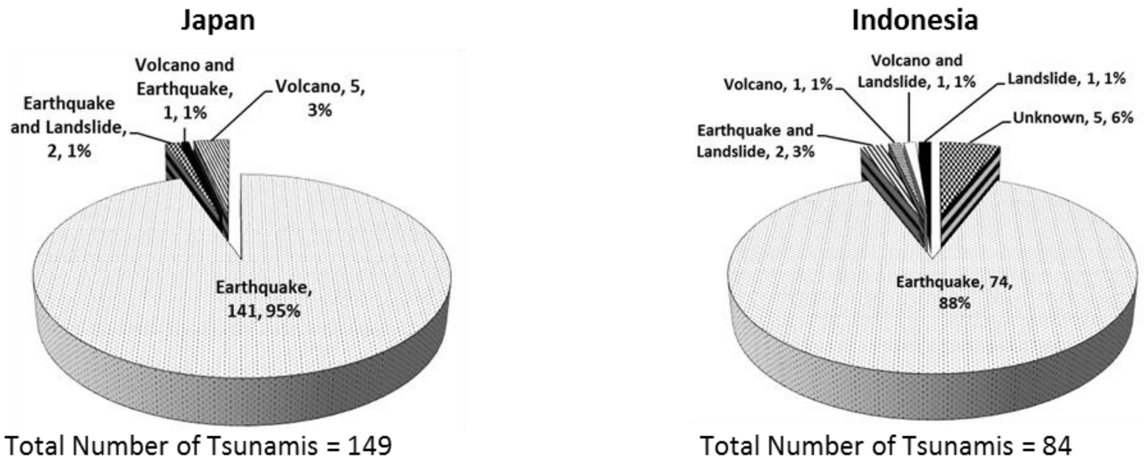


Figure 2.8 **Share of causes of tsunamis in Japan and Indonesia, 1900-2012.**

To better analyze the patterns of earthquakes and tsunamis in Japan and Indonesia, we divide the whole period into three periods, period I: 1900-1937, period II: 1938-1975 and period III: 1976-2012. By dividing the whole period into three sub-periods with almost equal length of 36 or 37 years, we try to investigate the historical trend of these natural disasters. However, as we described in the beginning of section 2.2, we need to take e.g. technology progress related to earthquake measurement such as earthquake monitoring devices.

Table 2.2 presents the basic statistics on the frequency of earthquakes and tsunamis in Japan and Indonesia from 1900 to 2012. In this period there are years without any disasters caused by earthquakes or tsunamis. Different patterns can be observed. In Japan, the frequency of tsunamis increased 110.34% from period I to II and declined around 3.28% in period III. In Indonesia, the frequency of tsunamis declined 28.57% from period I to II and increased about 80% in period III.

Table 2.2 **Basic statistics on the frequency of earthquakes and tsunamis.**

Japan

Period	Earthquake				Tsunami			
	Total	Mean	Std. Dev	Max	Total	Mean	Std. Dev	Max
I	53	1.39	1.37	5	29	0.76	1.22	5
II	71	1.87	2.32	11	61	1.61	2.13	10
III	97	2.62	2.20	8	59	1.59	1.28	4
All	**221**	**1.96**	**2.05**	**11**	**149**	**1.32**	**1.63**	**10**

Indonesia

Period	Earthquake				Tsunami			
	Total	Mean	Std. Dev	Max	Total	Mean	Std. Dev	Max
I	61	1.61	1.20	4	28	0.74	0.79	3
II	46	1.21	1.26	4	20	0.53	0.86	3
III	139	3.76	2.92	12	36	0.97	1.30	5
All	**246**	**2.18**	**2.23**	**12**	**84**	**0.74**	**1.02**	**5**

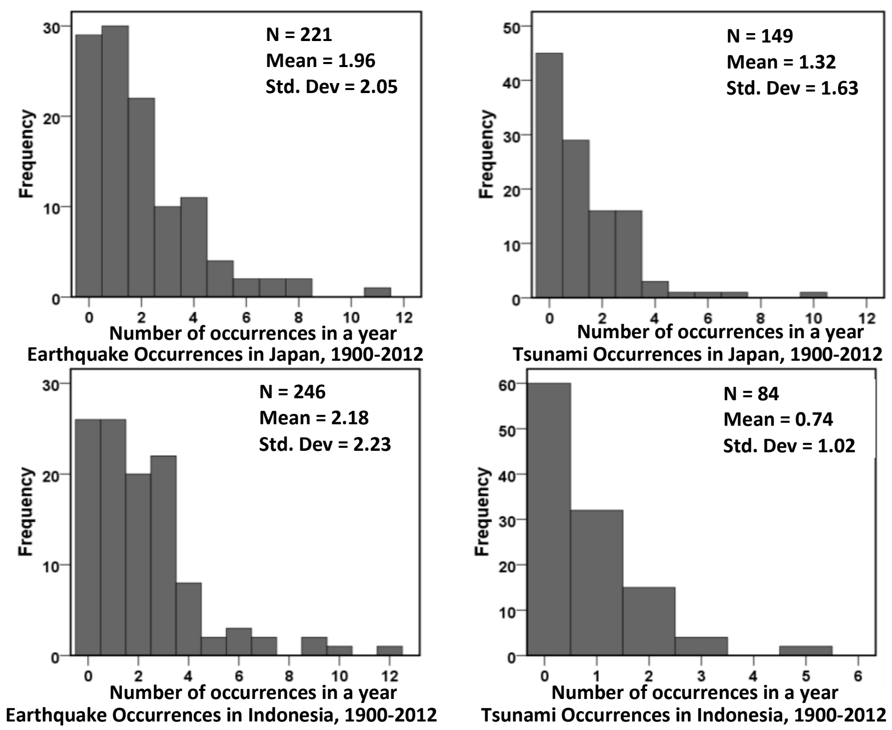


Figure 2.9 **Histogram of the annual frequency of earthquakes and tsunamis occurred in Japan and Indonesia.**

Figure 2.9 displays the histogram of the frequency of earthquakes and tsunamis, which occurred in Japan and Indonesia from 1900 to 2012 by year. In Figure 2.9, the horizontal coordinate indicates the number of earthquakes and tsunamis in each year, while the vertical coordinate shows the number of years corresponding to each frequency. We can see that earthquakes and tsunamis are rather rare events as in almost 80% of the years they occur less than twice a year.

The trend of earthquakes with magnitude 5Mw and above and their epicenter location in Japan is depicted in **Figure 2.10**. In Japan, this has an almost linear trend of increases in total occurrences, where from period I to period II the total number increased 33.96%, and increased again to 36.62% in period III. However, in terms of the epicenter location, which is divided into offshore/sea and mainland, the trends are not totally linear. The data reveal that the percentage of sea epicenters increased 11.37% between period I and II but decreased about 12.44% between period II and III.

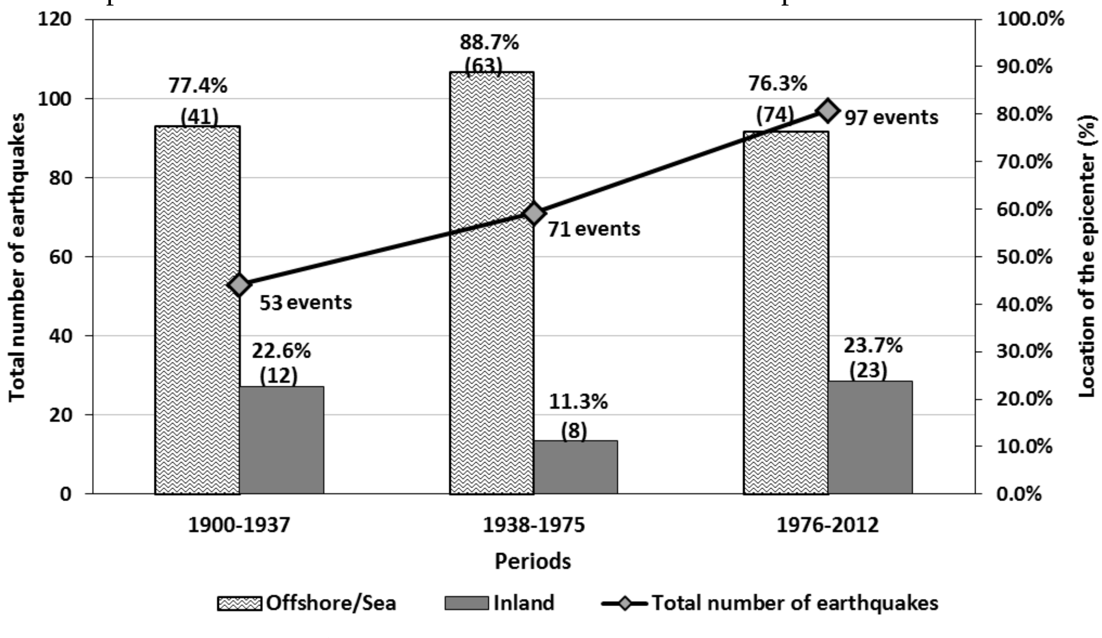


Figure 2.10 **Trend of earthquakes (Magnitude ≥ 5Mw) occurrences during 1900-2012 in Japan.**

In Indonesia, as shown in **Figure 2.11**, the trend of total earthquake occurrences is not linear, where from period I to II the total number decreased 23.33%, but then increased more than threefold to 202.17% in period III. In terms of the epicenter location, the trend is also not linear. The data show that the percentage of sea epicenters increased 3.9% between period I and II but decreased 14.9% between period II and III.

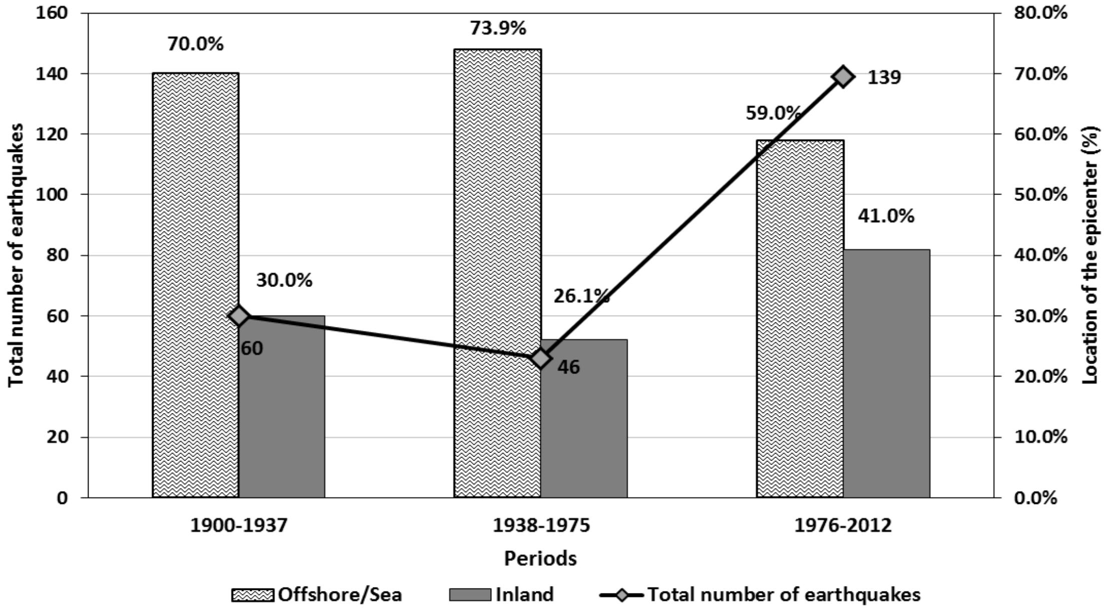


Figure 2.11 **Trend of earthquakes (Magnitude ≥ 5Mw) occurrences during 1900-2012 in Indonesia**

Table 2.3 **Basic statistics on the inter-occurrence between two consecutive occurrences of earthquakes and tsunamis (days)**

Japan

Period	Earthquake						Tsunami					
	Total	Mean	Std. Dev	CV	Max	Min	Total	Mean	Std. Dev	CV	Max	Min
I	13500	259.62	312.04	1.202	1314	0	12924	461.57	616.91	1.337	2769	0
II	13993	197.08	257.82	1.308	1345	0	13701	224.61	293.36	1.306	1417	0
III	13478	138.95	190.27	1.369	1000	0	13825	234.32	278.75	1.190	1347	0
All	**40971**	**186.23**	**249.19**	**1.338**	**1345**	**0**	**40450**	**273.31**	**379.51**	**1.389**	**2769**	**0**

Indonesia

Period	Earthquake						Tsunami					
	Total	Mean	Std. Dev	CV	Max	Min	Total	Mean	Std. Dev	CV	Max	Min
I	13815	230.25	244.61	1.062	931	0	13544	501.63	482.61	0.962	2272	30
II	13609	295.85	352.34	1.191	1461	1	11432	571.60	861.68	1.507	3085	1
III	13679	98.41	124.35	1.264	640	0	15753	437.58	695.67	1.590	3099	0
All	**41526**	**167.77**	**230.00**	**1.371**	**1461**	**0**	**40729**	**490.71**	**674.78**	**1.375**	**3099**	**0**

Note: CV = Coefficient of Variation

Table 2.3 lists the inter-occurrence times (in days) between two consecutive occurrences of earthquakes and tsunamis in Japan and Indonesia from 1900 to 2012. The higher the number is, the longer the duration between two consecutive earthquakes and tsunamis becomes. From **Table 2.3** we find that the average number of days between two consecutive tsunamis in Japan was about half of that in Indonesia. This finding conforms to the results of a study by Suppasri A, et al. (2012).

Unlike the case of tsunamis, the average inter-occurrence time between two consecutive earthquakes in Indonesia is smaller than that in Japan, which implies that earthquakes are relatively more frequent in Indonesia than in Japan. However, in general, both earthquakes and tsunamis show the same patterns in Japan and Indonesia; namely, they show a declining trend in the average of inter-occurrence times. Once again, it is a warning that the frequency of occurrences of these two natural disasters will be more frequent in the future.

Table 2.4 shows the basic statistics of D&M caused by earthquakes and tsunamis that occurred in Japan and Indonesia from 1900 to 2012. As we mentioned in section 2.1, there are a number of earthquakes and tsunamis without any casualties. Due to the extremely large D&M for the 2011 Great East Japan tsunami, the 2004 Indian Ocean tsunami, and the 1923 Great Kanto earthquake, we exclude these cases in the D&M data in **Table 2.4**. For the whole period, the average D&M of earthquakes in Japan is 0.57 people per day, while in Indonesia it is 0.39 people per day. And the average D&M of tsunamis in Japan is 0.28 people per day, while in Indonesia it is 0.19 people per day. Incidentally, in case we include the three extreme earthquakes and tsunamis mentioned above, we find the following: (i) if we include the 1923 earthquake data for Japan, the corresponding mean increases from the current 0.28 to 7.44, while the corresponding standard deviation rises from 25.98 to 843.52. (ii) If we include the 2004 tsunami data for Indonesia, the corresponding mean increases from the current 0.46 to 13.53, while the corresponding standard deviation rises from 22.78 to 1502.65. (iii) If we include the 2011 tsunami data for Japan, the corresponding mean increases from the current 0.07 to 1.51, while the corresponding standard deviation rises from

5.32 to 165.81. Thus, we can conclude that the basic statistic data would be misleading with a certain amount of confusion if we include these extremely unusual disaster data. As a conclusion, **Table 2.4** reveals that, even though the average D&M of tsunamis in Japan is relatively higher than in Indonesia for the whole period, the trend of the average D&M from period I to III in Japan exhibits a declining trend, whereas in Indonesia it shows an increasing trend. For the case of earthquakes, although at earlier period, Japan had a relatively higher average of D&M compared to that in Indonesia, in the last period the opposite result is observed.

Table 2.4 **Basic statistics of the number of deaths and missing people caused by earthquakes and tsunamis**

Japan

Period	Earthquake				Tsunami			
	Total	Mean	Std. Dev	Max	Total	Mean	Std. Dev	Max
I	3,950	0.28	25.98	3,022	5,389	0.39	32.29	3,022
II	11,579	0.83	51.60	5,131	5,242	0.38	31.02	3,358
III	7,832	0.59	50.92	5,502	865	0.07	5.32	441
All	**23,361**	**0.57**	**44.35**	**5,502**	**11,496**	**0.28**	**26.23**	**3,358**

Indonesia

Period	Earthquake				Tsunami			
	Total	Mean	Std. Dev	Max	Total	Mean	Std. Dev	Max
I	2,489	0.18	14.21	1500	639	0.05	3.67	400
II	510	0.04	2.10	213	959	0.07	5.58	600
III	13,009	0.97	58.85	5,749	6,087	0.46	22.78	1669
All	**16,008**	**0.39**	**31.81**	**5,749**	**7,685**	**0.19**	**13.51**	**1,669**

These conditions reflect the process of some preparedness against natural disasters, which have been conducted in a sustainable manner in Japan, namely the construction of earthquake-resistant buildings, the implementation of disaster preparedness drills, the building of sea walls, the provision of reliable EWS, the dissemination of disaster information, and the incorporation of disaster education in official curriculum guidelines. Efforts to improve the safety of buildings have taken a relatively long time; namely since 1919 when the urban building law was enacted to provide minimum requirement for structural safety for the first time. The processes to make people safer still continue as a reflection of learning from disasters.

2.3 Mathematical Model Analyses for Earthquakes and Tsunamis

2.3.1 Modeling Inter-Occurrence Times of Earthquakes and Tsunamis

The timing and magnitude of natural disasters are both unpredictable and contain great uncertainty; thus, we know that the phenomena of natural disasters are “stochastic” in principle. Uncertainty is a critical element in the model analysis related with natural disasters (Kossobokov, 2012). Although they are very hard to predict, natural disasters such as earthquakes and tsunamis can be analyzed using probability models to guide decision makers on how to quantitatively describe the nature of earthquakes and tsunamis. In this section, historical data of earthquakes and tsunamis will be used as the source for building probability models. As for the timing of these two types of natural disasters, data on inter-occurrence times will be used, and as for the magnitude of earthquakes and tsunamis, data on the number of D&M will be used. **Figure 2.12** and **Figure 2.13** depict the inter-occurrence times between two consecutive earthquakes in Japan and Indonesia, respectively, in descending order from 1900 to 2012. In Japan, the average number of days between earthquakes is 186.23 days, whilst, in Indonesia, it is 167.77 days.

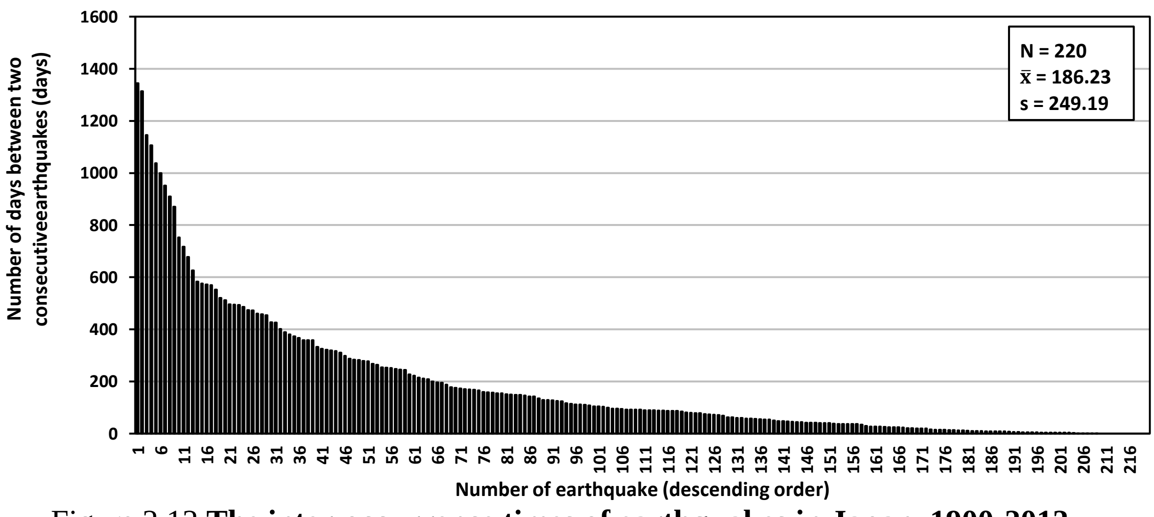


Figure 2.12 **The inter-occurrence times of earthquakes in Japan, 1900-2012.**

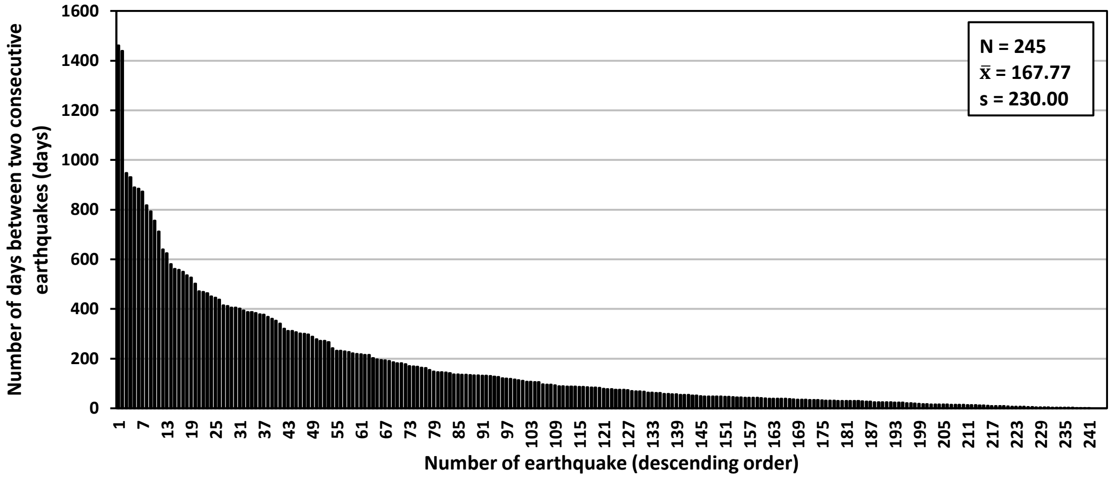


Figure 2.13 **The inter-occurrence times of earthquakes in Indonesia, 1900-2012.**

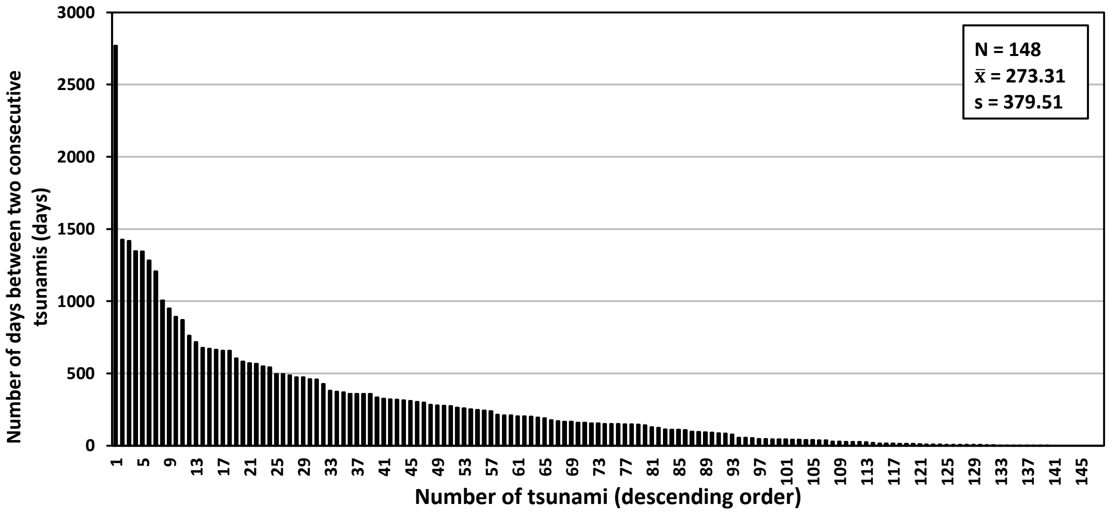


Figure 2.14 **The inter-occurrence times of tsunamis in Japan, 1900-2012.**

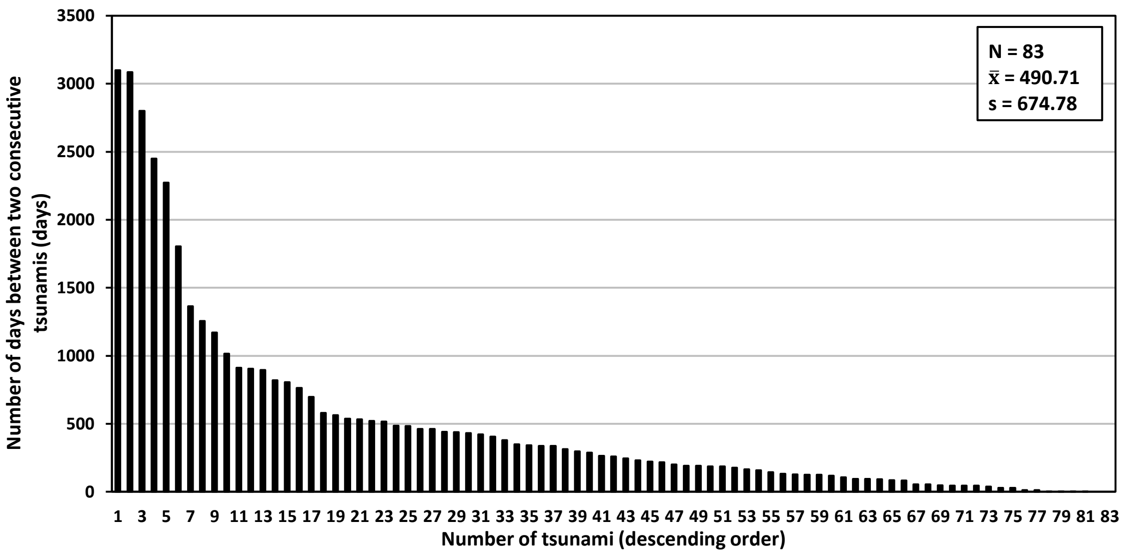


Figure 2.15 **The inter-occurrence times of tsunamis in Indonesia, 1900-2012.**

To align with the previous discussion, **Figure 2.14** and **Figure 2.15** present an overview of the inter-occurrence times between two consecutive tsunamis in Japan and Indonesia, in descending order from 1900 to 2012, respectively. In Japan, the average number of days between tsunamis is 273.31 days; whilst in Indonesia it is 490.71 days.

Figures 2.12-2.15 show that the numbers of days between consecutive earthquakes and tsunamis are generally long meaning that earthquakes and tsunamis are rare events. A common distribution to model waiting times between occurrences of rare events is exponential distribution; and we will prove this in the following analysis. In order to develop parameters to describe the data from earthquakes and tsunamis, the data will be analyzed by comparing them to various probability distributions and then a standard distribution will be chosen that provides a close "fit" to the set of theoretical probability distributions (Vose, 2010). To assess which probability distribution is best, the Chi-square test will be used, a lower Chi-square value indicates the best fitting probability distribution (Gaustad et al., 2008).

Our estimation procedure is as follows: first, we try to find the best fitting probability distribution for modeling the inter-occurrence times between two consecutive earthquakes or tsunamis and D&M data from among various probability distributions including exponential, normal, and log-normal. Then applying the Chi-square test, probability distributions with lower Chi-square values are shown in **Tables 2.5** and **2.8**, respectively. Following Uriu and Oyama (2011), we apply the application software "Best Fit" to find the appropriate probability distribution that best fits the actual data depicted in **Figures 2.12-2.15**. The result in **Table 2.5** reveals that the exponential distribution fits best to the actual data of the inter-occurrence times of earthquakes and tsunamis in Japan and Indonesia.

Table 2.5 **Fitness of probabilistic model for the inter-occurrence times of earthquake and tsunami in Japan and Indonesia**

Period	Rank / Test	Earthquake 1	Earthquake 2	Earthquake 3	Tsunami 1	Tsunami 2	Tsunami 3
Japan							
All	Chi-sq	*Exp*	Log	Norm	*Exp*	Log	Norm
		68.44	190.2	233.4	*59.65*	97.42	235.1
I	Chi-sq	*Exp*	Log	Norm	*Exp*	Log	Norm
		8.23	29.69	35.92	*4.14*	21.29	22.57
II	Chi-sq	*Exp*	Log	Norm	*Exp*	Norm	Log
		31.39	89.99	94.77	*28.26*	49.51	77.25
III	Chi-sq	*Exp*	Log	Norm	*Exp*	Log	Norm
		14.02	68.23	88.87	*9.49*	20.47	28.41
Indonesia							
All	Chi-sq	*Exp*	Log	Norm	*Exp*	Log	Norm
		49.47	229.6	334.9	*7.25*	49.66	79.88
I	Chi-sq	*Exp*	Log	Norm	*Exp*	Log	Norm
		12.60	30.00	36.00	*1.70*	5.78	8.74
II	Chi-sq	*Exp*	Log	Norm	*Exp*	Log	Norm
		5.83	23.91	33.65	*2.80*	2.80	27.60
III	Chi-sq	*Exp*	Log	Norm	*Exp*	Log	Norm
		19.53	96.96	132.5	*7.56*	19.22	37.50

The probability density function (pdf) of an exponential distribution is:

$$y = \lambda e^{-\lambda x}, \qquad (2.1)$$

where:

x: the inter-occurrence times between two consecutive occurrences (days),

y: occurrence probability,

λ: parameter.

The properties of an exponential distribution are Mean (μ) = $1/\lambda$ and Variance (σ^2) = $1/\lambda^2$.

Table 2.6 gives the estimate of the parameter λ for the inter-occurrence times of earthquakes and tsunamis in Japan from 1900 to 2012. For earthquakes, we obtain 0.00537, 0.00385, 0.00507, and 0.0072 for the whole period, period I, II and III, respectively. Hence, the expected interval period between two earthquake occurrences for the whole period is $1/\lambda$ = 186.22 days, while for period III it is $1/\lambda_{III}$ = 138.89 days, which is shorter than in period I: $1/\lambda_I$ = 259.74 days. For tsunamis, we obtain 0.00366, 0.00217, 0.00445, and 0.00427 for the whole period, period I, II, and III, respectively. Then, the expected interval period between two tsunami occurrences for the whole period is $1/\lambda$ = 273.22 days, while for period III it is $1/\lambda_{III}$ = 234.19 days, which is about half that in period I: $1/\lambda_I$ = 460.83 days.

Table 2.6 **Estimate of parameters for estimating the inter-occurrence times of earthquakes and tsunamis in Japan**

	Earthquake				**Tsunami**			
	All	Period I	Period II	Period III	All	Period I	Period II	Period III
λ	0.00537	0.00385	0.00507	0.00720	0.00366	0.00217	0.00445	0.00427
$1/\lambda$	186.22	259.74	197.24	138.89	273.22	460.83	224.72	234.19

Table 2.7 shows the estimate of the parameter λ for the inter-occurrence times of earthquakes and tsunamis in Indonesia during 1900-2012. For earthquakes, we obtain 0.00596, 0.00434, 0.00338, and 0.01016 for the whole period, period I, II and III, respectively. Therefore, the expected interval period between two earthquake occurrences for the whole period is $1/\lambda$=167.79 days, while for period III it is $1/\lambda_{III}$=98.43 days, which is less than half of the inter-occurrence time in period I: $1/\lambda_I$=230.41 days. For tsunamis, we obtain 0.00204, 0.00199, 0.00175, and 0.00229 for the whole period, period I, II, and III, respectively. Then, the expected interval period between two tsunami occurrences for the whole period is $1/\lambda$=490.20 days, while for period III it is $1/\lambda_{III}$=436.68 days, which is relatively shorter than in period I: $1/\lambda_I$=502.51 days.

The results in **Table 2.6** and **Table 2.7** are in accordance with **Table 2.3**, in which from the expected inter-occurrence times, we should be aware that in the future, these two natural disasters are expected to become more frequent in Japan and

Indonesia. Furthermore, we will add on the above mathematical modeling analysis that our "about 120 years" and "about 40 years" period data analyses are mainly focused on investigating the "recent" trend of the natural disasters such as earthquake and tsunami with respect to their occurrences and damages based on the data measured under the almost same conditions. Thus, considering that these natural disasters' analysis needs much longer range such as several hundred years or more, we believe we have to be cautious about reliability and accuracy of our parameter estimates, model results, and so on.

Table 2.7 **Estimate of parameters for estimating the inter-occurrence times of earthquakes and tsunamis in Indonesia**

	Earthquake				**Tsunami**			
	All	Period I	Period II	Period III	All	Period I	Period II	Period III
λ	0.00596	0.00434	0.00338	0.01016	0.00204	0.00199	0.00175	0.00229
$1/\lambda$	167.79	230.41	295.86	98.43	490.20	502.51	571.43	436.68

2.3.2 Modeling Fatalities of Earthquakes and Tsunamis

Next, we also model the number of D&M as fatalities caused by earthquakes and tsunamis in Japan and Indonesia using the probabilistic model. The D&M caused by these two natural disasters measures the magnitude of disasters. To model the D&M, we include all days from 1900 to 2012, which total more than 40,000 days. Our objective is to estimate the number of D&M per day. However, since earthquakes and tsunamis are rare events and did not always cause D&M, we will analyze the number of D&M per month. The parameters for both distributions are estimated using the method of maximum likelihood. The Chi-square goodness of fit test will be used to determine the appropriate distribution to the data.

Table 2.8 shows the results of the fitness of the probabilistic model for the D&M per month caused by earthquakes and tsunamis. The results show that the Poisson and negative binomial distribution fit the actual data of D&M per month in Japan and Indonesia. It appears that the negative binomial has Chi-square values smaller than the Poisson. However, since earthquakes and tsunamis are rare events, unpredictable and stochastic natural phenomena as described in section 2.2, in terms of $p \to 0$ and $n \to \infty$, taking the limit so that $\lambda = np$, we know we can approximate the probability of the Negative Binomial by the Poisson distribution (Sakamoto et al., 1986). Therefore, we conclude that the number of D&M follow the Poisson distribution. However, regarding our estimates given in **Table 2.8**, we believe that the estimate values should have certain ranges surrounding them due to the uncertainty rather than insisting on these exact estimates.

Table 2.8 **Fitness of probabilistic model for number of deaths and missing people of earthquakes and tsunamis**

Period	Rank / Test	Earthquake 1	Earthquake 2	Tsunami 1	Tsunami 2
Japan					
All	Chi-sq	NegBin	*Poisson*	NegBin	*Poisson*
		849.2	1,302	*944.2*	1,390
I	Chi-sq	NegBin	*Poisson*	NegBin	*Poisson*
		225.7	311.3	54.77	*58.49*
II	Chi-sq	NegBin	*Poisson*	NegBin	*Poisson*
		123.9	152.8	500.8	*948.3*
III	Chi-sq	NegBin	*Poisson*	*Poisson*	NegBin
		256	402.9	*383.2*	387
Indonesia					
All	Chi-sq	*Poisson*	NegBin	NegBin	*Poisson*
		2,118	*2,520*	*257.3*	288.6
I	Chi-sq	NegBin	*Poisson*	NegBin	*Poisson*
		106.8	124.8	*103.7*	118.2
II	Chi-sq	NegBin	*Poisson*	*Poisson*	NegBin
		74	83.23	*93.8*	105.7
III	Chi-sq	*Poisson*	NegBin	NegBin	*Poisson*
		1,163	1,273	*249.8*	352.7

The Poisson distribution specifies a stochastic counting process that represents the total number of events that have occurred up to time *t* (Winston, 2003). The probability density function of the Poisson distribution is as follows:

$$y = \frac{e^{-\lambda}\,\lambda^{x}}{x!} \tag{2.2}$$

where:

x: number of deaths and missing people (D&M),

y: probability of deaths and missing people,

λ: parameter.

The properties of the Poisson distribution are Mean (μ) = λ and Variance (σ^2) = λ.

Table 2.9 presents the parameter estimates (λ) for D&M caused by earthquakes and tsunamis. In interpreting the estimated parameter, one should always remember that as we have mentioned in the early part of section 2.3, uncertainty is always unavoidable in the model analysis of natural disasters. Thus, the estimated parameter should be interpreted cautiously and judiciously. The estimated parameter (λ) interpretations are as follows; for the earthquakes case, the average of D&M in Japan for the whole period is 17.330 people per month or 0.578 people per day, and for period I, II, and III they are 8.623, 25.393, and 18.005 people per month, respectively. In addition, for Indonesia the average of D&M from 1900 to 2012 is 11.849 people per month or 0.395 people per day, while for period I, II and III they are 5.458, 1.118, and 29.633 people per month, respectively. Although, in period I the average of D&M in Japan is larger than in Indonesia, in period III the opposite occurred.

Table 2.9 **Estimate of parameters (λ) for estimating the number of D&M caused by earthquakes and tsunamis**

	Earthquake				Tsunami			
	All	Period I	Period II	Period III	All	Period I	Period II	Period III
Japan	17.330	8.623	25.393	18.005	8.535	11.818	11.496	1.989
Indonesia	11.849	5.458	1.118	29.633	5.705	1.401	2.103	13.993

For the tsunamis case, in Japan, the average number of D&M of tsunami from 1900 to 2012 is 8.535 people per month or 0.284 people per day, and for period I, II and III they are 11.818, 11.496, and 1.989 people per month, respectively. In Indonesia, the average number of D&M of tsunami for the whole period is 5.705 people per month or 0.19 people per day, and for period I, II and III they are 1.401, 2.103, and 13.993 people per month, respectively. Here, there is an opposite pattern of D&M between Japan and Indonesia; namely, while in Japan the average number of D&M of tsunamis shows a decreasing trend; in Indonesia it exhibits an increasing trend. This could be a warning that the number of people threatened by tsunamis in Indonesia has increased. Referring to **Table 2.4**, the estimated number of D&M caused by earthquakes and tsunamis in **Table 2.9** is almost the same.

By using the estimated average number of deaths as in **Table 2.9** and the return period of a great event and if we also do not consider any change in the countermeasures, we can estimate future loss for a specific location and event. We define a great event as an earthquake with moment magnitude 8Mw and above. For the return period of the event we will use the return period of an earthquake with moment magnitude of 8.1-8.8Mw calculated by Yegulalp (2010) for Japan. In Japan from 1900 until 2012, there have been 12 earthquakes with magnitude 8.0Mw and above, of which 7 earthquakes generated tsunami. According to Yegulalp (2010) the return period of an 8.8Mw earthquake in Japan is 220 years. The last great earthquake in Japan that also generated tsunami is the 2011 Great East earthquake and tsunami, with its epicenter off the Pacific coast of Tohoku. Given that the estimated average number of D&M per day of tsunamis in Japan is 0.284 and the return period of an 8.8Mw or 9.0Mw earthquake is 220 years, which most probably will also generate a tsunami, there will be about 22,000 deaths in Tohoku.

We know from the trend of D&M of earthquakes and tsunamis that Japan and Indonesia are both topographically located on the Ring of Fire, which also makes Indonesia face a high threat of earthquakes and/or tsunamis, as well as volcanic eruptions. Nevertheless, it seems the community in Indonesia less anticipates these threats. As a result, each disaster has always caused casualties in large numbers. Indonesia can learn from Japan about the handling of earthquakes and tsunamis.

Of the countries in the world that have the highest frequency of earthquakes and tsunamis, Japan has the most advanced hazard warning system (UNESCO, 2012, Suppasri et al., 2012, and Parlak et al., 2012). The awareness and education of natural disasters should also be given and included as one of the subjects in schools starting from elementary school. Disaster preparedness exercises should be carried out regularly and continuously. Reliable EWS should also be provided, especially in disaster prone areas. According to Parlak et al. (2012), despite their short warning times, EWS, such as for earthquakes, can become very useful means in risk mitigation. Hence, when a disaster occurs, people instantly know what to do and what not to do. The cause of a high number of D&M is unpreparedness when disaster strikes, resulting in panic.

CHAPTER III

MAJOR FACTORS AFFECTING HUMAN CASUALTIES AND RECOVERY POLICY REVIEW

This chapter is a continuation of the previous chapter, which is included in the activities carried out during the first phase of disaster management. In this chapter, we investigate the relationship between the number of death and missing people (D&M) and some parameters of natural disasters with case studies of earthquakes and tsunamis. In addition, in Chapter III, we also briefly review the recovery process from the 2004 Aceh tsunami and the 2011 Tohoku tsunami. Analysis in more detail and depth associated with the recovery process of the 2011 Tohoku earthquake and tsunami will be presented in Chapter IV.

3.1 Natural Disasters in A Global Perspective

As mentioned in Chapter I that in the last four decades, based on the International Disaster Database (EM-DAT), between 1970-1979 and 2000-2012, the number of natural disaster events[11] reported globally increased significantly from 837 to 4,939 or increased almost six times. Over the whole period of 1970-2012, 40.8 percent of these natural disasters occurred in Asia. **Figure 3.1**, which is a replicate of **Figure 1.2**, portrays the increasing of natural disasters reported by region of continent. Such increases are allegedly associated with the increasing of population exposed to hazards (UN-ESCAP, 2010).

Figure 3.1 also portrays that the frequencies of natural disaster from 1970 to 2005 shows increase trend in all regions. Nevertheless, it seems that there is a turning

[11]The natural disasters include geophysical, climatological, hydrological, and meteorological.

point in 2005, in which from 2005 in most of the regions, the frequencies of natural disaster started to show declining trend, a fairly significant decline could be seen in Asia, namely, the average growth of natural disaster events (slope of the regression line) in Asia has decreased from 3.86 into -5.02. Only in Africa that the number of natural disaster during 1970-2012 shows consistent increase, whilst in Oceania the trend is rather flat. In terms of casualties, however, Asia was proportionally hit harder. Of all the number of D&M caused by natural disasters in the world from 1970 to 2012, as much as 57.45% is in Asia, followed by Africa (21.65%) and Americas (15.07%) as described in **Table 3.1**.

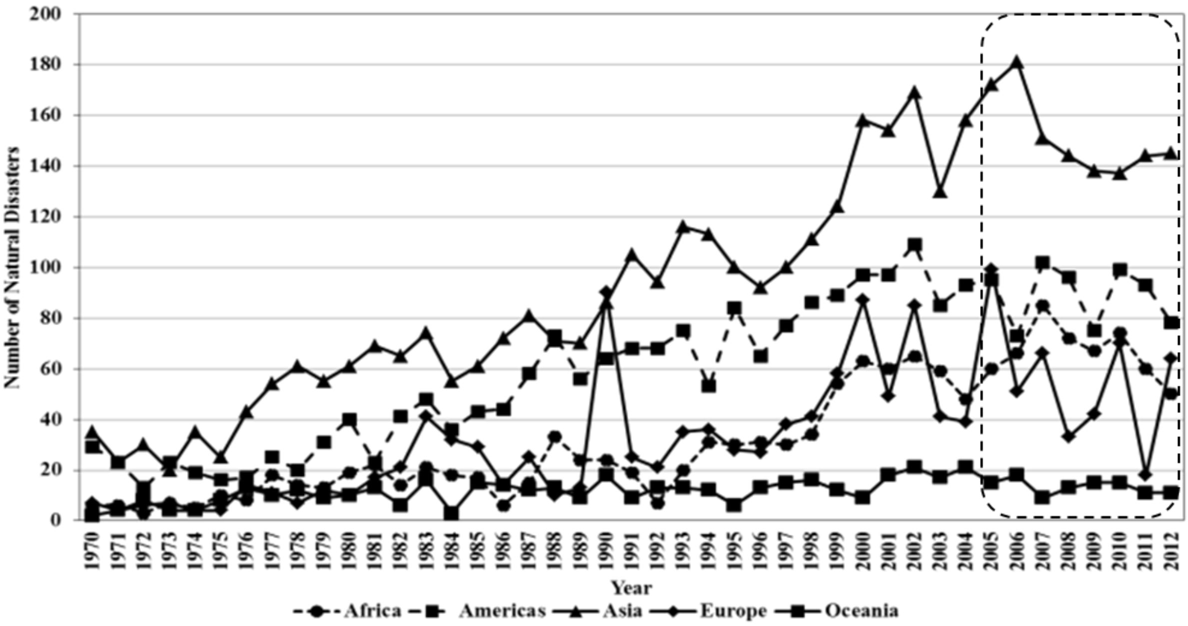


Figure 3.1 **Number of natural disaster reported, 1970-2012.**

Table 3.1. **Natural disasters events and impacts, 1970-2012.**

Region	Events	Death and Missing people	Affected People (000)	Damage (US$ millions)
Africa	1,388	710,821	438,219	26,104.53
Americas	2,599	494,744	243,672	914,442.81
Asia	4,082	1,885,899	5,900,107	1,137,363.40
Europe	1,431	185,311	38,400	333,816.11
Oceania	505	5,964	20,957	70,669.17
Total	**10,005**	**3,282,739**	**6,641,355**	**2,482,396.01**

Source: International Disaster Database (EM-DAT)

Given the damage and costs that natural disasters can bring, it is important to understand the “nature” of disasters in order to assist policy makers and planners who are involved in disaster preparedness and mitigation (Oyama and Uriu, 2011). Many studies have been conducted to investigate the natural disasters, especially earthquakes and tsunamis, yet, to our best knowledge, nothing has been done on investigating the influence of the parameters of earthquake and tsunami to the number of D&M. The parameters may include the epicenter location, earthquake magnitude, depth of hypocenter, and water height. It should be note that not every earthquake and tsunami that occurs will inflict D&M and/or property loss/damage. Earthquake or tsunami that occurred in the unpopulated region is certainly not a natural disaster, but rather just a natural phenomenon. This study is also significant as part of the disaster risk analysis and assessment, moreover Japan faces the highest tsunami risk followed by Indonesia (Suppasri et al., 2012).

The number of victims, which comprise of number of deaths and missing people and affected people, and amount of property damages caused by natural disasters often used to scale and categorize the disasters. **Figure 3.2** shows the trend of natural disasters which categorized by number of victims (killed and affected). During the period of 1970 and 2012, there was an increase in all categories of natural disasters victims. Natural disasters creating less than 1,000 victims remained the most numerous during the entire period. Their increase is the most pronounced. With the average of events equal to 61, their number increased three times between 1970 and 2012. Before 1992, there is no distinction between the numbers in the categories of disasters causing between 1,000 and 999,999 victims. However, starting from 1992, natural disasters causing 1,000 to 9,999 and 10,000 to 99,999 victims show significant increases which differentiate them from those causing 100,000 to 999,999 victims. In 1997-2008, the differentiation between these categories of natural disasters becomes clear as well as the differentiation in the evolution of their numbers. Natural disasters causing 1,000 to 9,999 victims show the most pronounced evolution. Their number increased nine times from 1970 to 2012. Natural disasters inflicting 10 million victims or more remained rare, yet, their occurrence increased around two times between 1970 and 2012.

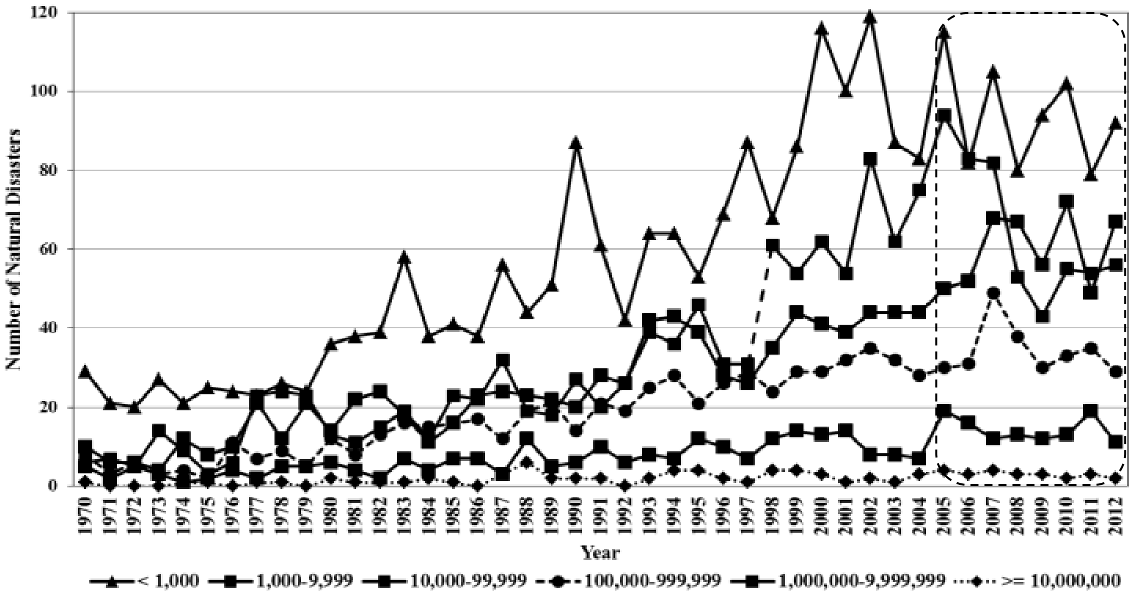


Figure 3.2 **Natural disasters categorized by number of victims, 1970-2012.**

If we grouping these six categories into three groups of victims' scale, namely small, medium and large, in which the 1st and 2nd category can be regarded as small, the 3rd and 4th as medium, and the 5th and 6th as large. Then we can see that after experiencing increase trend from 1970, there is a turning point in 2005, where the small group shows a declining trend, while the medium group moves into different direction, and the large group is relatively stable. Thus, it implies that the cause of the declining trend of the number of natural disasters in most of all regions as in **Figure 3.1** after 2005 is the declining trend of frequency of the number of victims in the small group.

During 1970-2012, 40.8% of natural disasters occurred in Asia, **Figure 3.3** shows that the three most frequent natural disasters in Asia during this period is floods, followed by storms and earthquakes, while the landslide and other natural disasters (drought, extreme temperature, volcano, and wildfire) are not frequent to occur. However, the order of the three most frequent natural disasters become reversed in terms of number of D&M inflicted by these natural disasters, as in **Figure 3.4**, earthquakes claim the highest percentage of D&M (48.46%), followed by storms (38.96%) and floods (10.06%), respectively. **Figure 3.3** also gives clear background of the cause of declining trend in Asia from 2005 as depicted in **Figure 3.1**. As the first and second most frequent natural disasters in Asia, flood and storm, show declining trend of events.

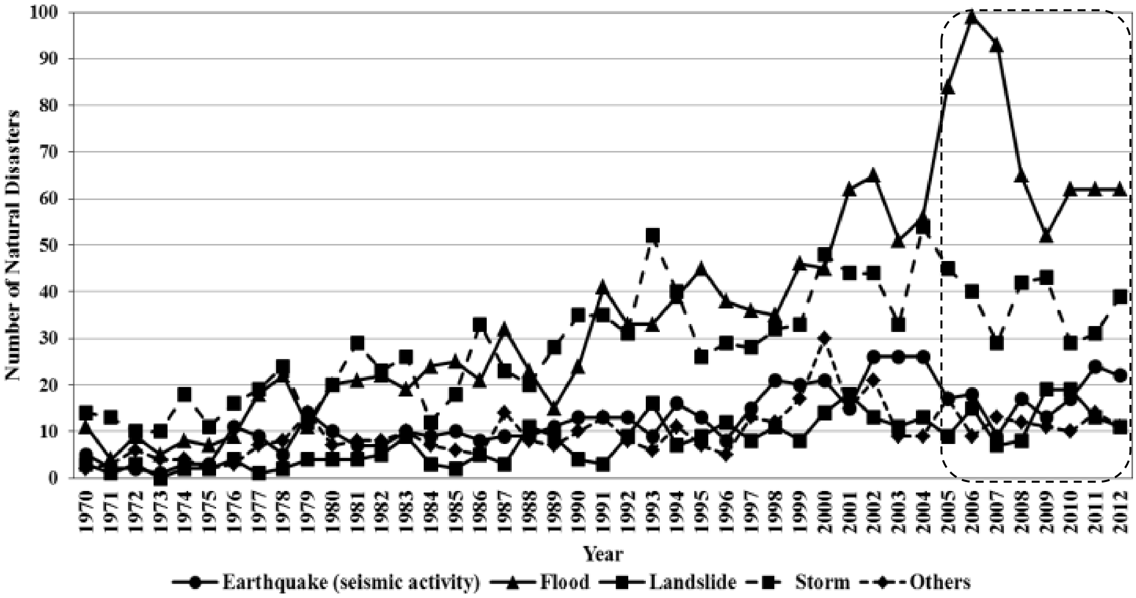


Figure 3.3 **Total number of natural disasters by type of natural hazard in Asia, 1970-2012.**

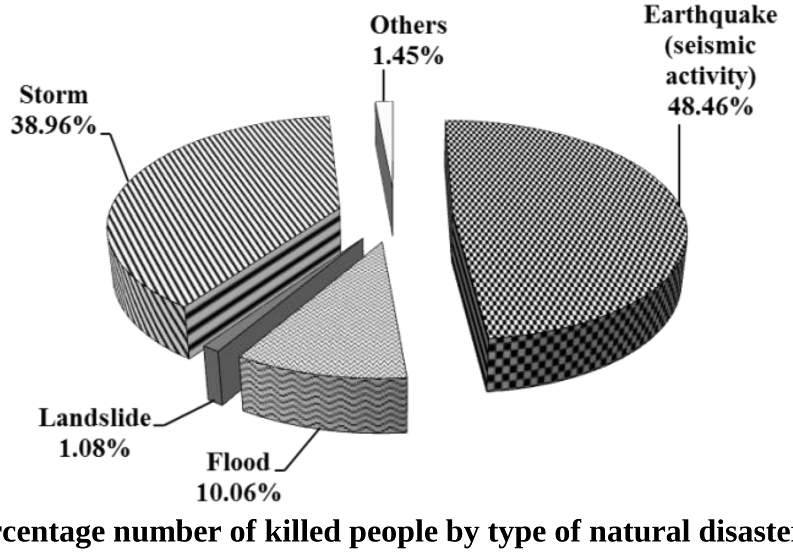


Figure 3.4**. Percentage number of killed people by type of natural disasters in Asia, 1970-2012.**

In this regard, the 2004 Aceh Tsunami and the 2011 Tohoku Tsunami are a well-known and latest example of these compound disasters. According to the Significant Earthquake Database (SED) both of these tsunamis was triggered by earthquakes with magnitude 9 Mw, in which the first was occurred of the west coast of Aceh, Indonesia and the latter was occurred of the Pacific coast of Tohoku, Japan. The epicenters of these great earthquakes are located on the ring of fire, and it is not a coincidence, because according to the U.S. Geological Survey, about 90% of the world's Earthquakes and 81% of the World's Largest Earthquakes occur along the Ring of Fire. Japan and Indonesia, in fact, lies on the Ring of Fire. Both of these earthquakes and tsunamis have caused not only destruction of property but also have inflicted large number of deaths in Japan and Indonesia, namely 19,648 and 172,761 D&M in Japan and Indonesia, respectively.

For the case study, as in Chapter II, in Chapter III we also use the data of earthquakes and tsunamis from 1900 to 2012 for Japan and Indonesia, respectively. For earthquakes, we use data from the Significant Earthquake Database (SED); while for tsunamis, data from the Global Historical Tsunami Database (GHTD) will be used. The database lists the date, cause, primary magnitude, coordinate of epicenter location, depth of hypocenter, maximum water height, and number of D&M. Based on the coordinate of epicenter location given, then we can categorize whether the earthquake is sea earthquake or mainland earthquake.

Figure 3.5 portrays the number of D&M caused by earthquakes and earthquake magnitude by location of epicenter in Japan and Indonesia, with the exception of the Great Kanto Earthquake in 1923. In **Figure 3.5** most of the earthquakes in Japan and Indonesia have epicenter locations at offshore/sea, namely 78.4% and 63.9% for Japan and Indonesia, respectively. However, not all these earthquakes caused human casualties; in Japan, only 58-recorded earthquakes caused D&M, while in Indonesia only 90-recorded earthquakes did so.

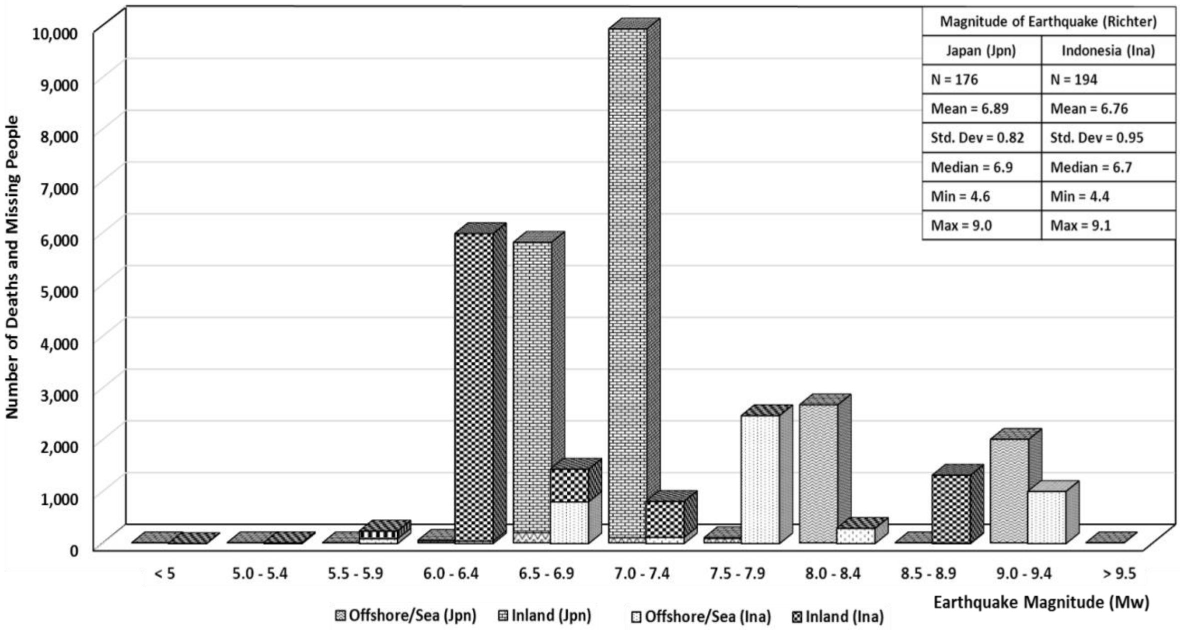


Figure 3.5**. Number of deaths and missing people caused by earthquakes in Japan and Indonesia by magnitude of earthquakes and location of epicenter, 1900-2012**

In general, **Figure 3.5** describes that earthquakes, which caused considerable D&M in Japan and Indonesia, are those with magnitude above 6.0 Mw. In addition, if we analyze further, of these earthquakes, earthquakes with magnitude between 6.0 and 7.4 Mw mostly have epicenters on the mainland, while earthquakes with magnitude 7.5 Mw and above mostly have epicenters at offshore/sea. This is a kind of evidence where the location of epicenter is a significant factor in causing D&M, an issue we will return in section 3.3.

The numbers of D&M inflicted by tsunamis from 1900 to 2012 in Japan and Indonesia are presented in **Figure 3.6**, with the exception of the 2004 Aceh tsunami and the 2011 Tohoku tsunami. As derived from the Japanese word, in Japan, the tsunami resulted in many human casualties in the initial period; however, this number seems began to decline in the mid-period. By contrast, in Indonesia, ranging from the mid-period, the death toll caused by tsunamis start to increase. At glance, **Figure 3.6** shows a sort of "mirror" in which the number of human victims in Indonesia nowadays is a reflection of the human toll in Japan in the past. This could be a warning that the number of people threatened by tsunamis in Indonesia has increased.

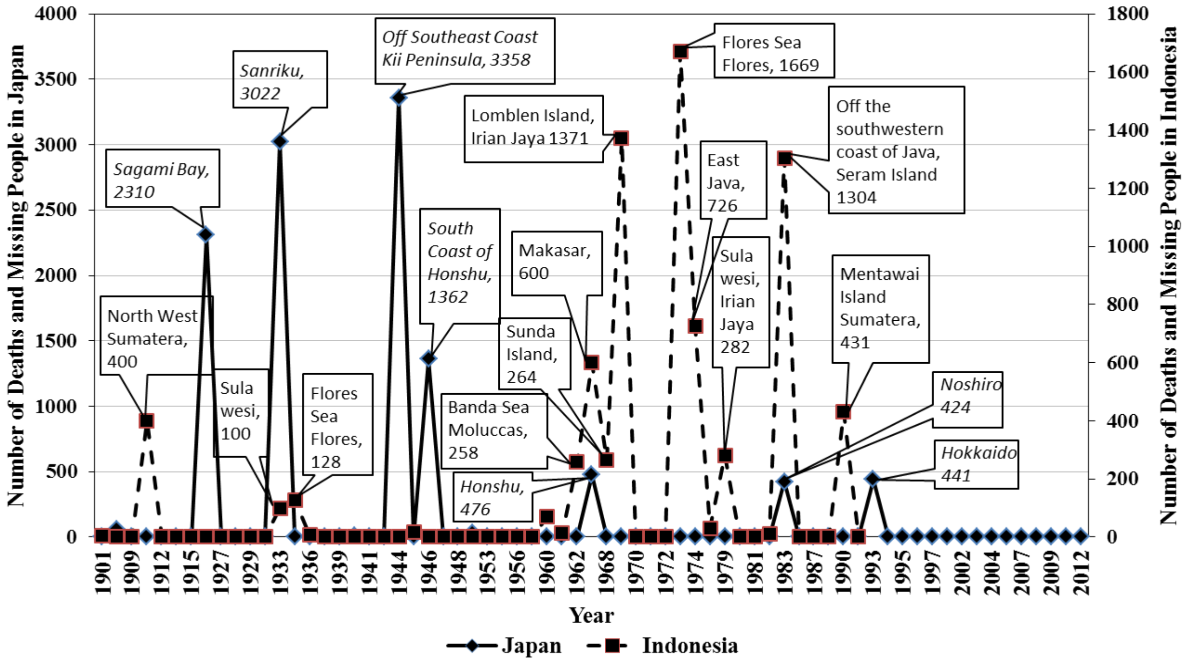


Figure 3.6 **Number of deaths and missing people caused by tsunamis in Japan and Indonesia**

As has been stated earlier that there are many factors contribute to the death toll from the earthquake and tsunami, **Figure 3.7** and **Figure 3.8** depict some of these factors. **Figure 3.7** shows the relationship between earthquake magnitude, focal depth, and number of D&M caused by earthquakes in Japan and Indonesia, with the exception of the Great Kanto Earthquake (1923). Whilst **Figure 3.8**, with the exception of tsunamis in Tohoku (2011) and Aceh (2004), has clearly described the relationship between earthquake magnitudes, maximum water height and number of D&M inflicted.

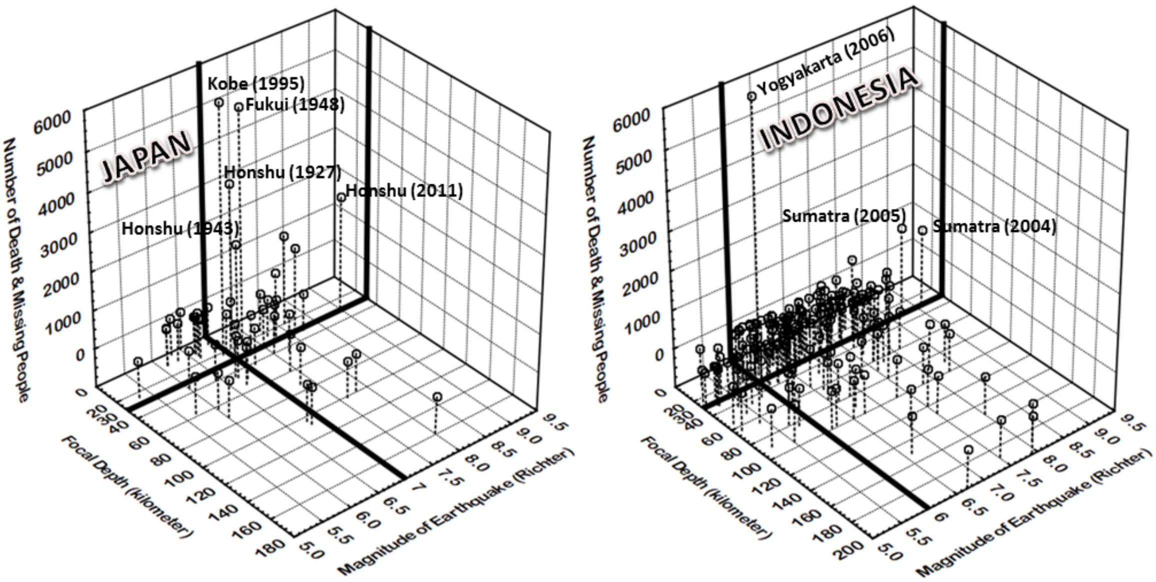


Figure 3.7. **3D Scatterplot of number of fatalities (D&M) caused by earthquakes.**

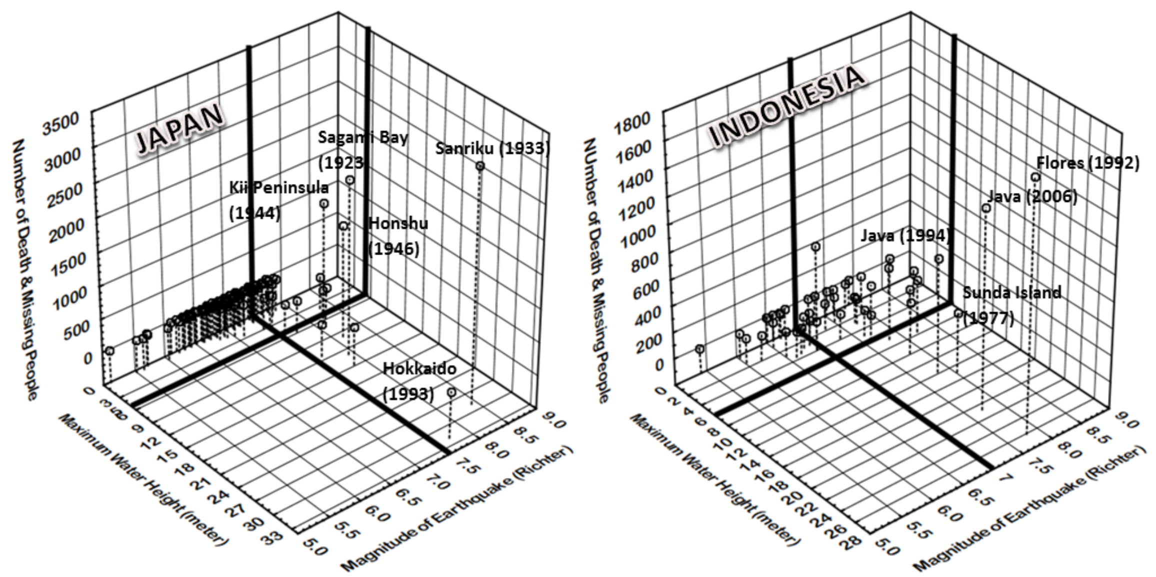


Figure 3.8. **3D Scatterplot of number of fatalities (D&M) caused by tsunamis.**

3.2 Mathematical Models to Estimate Fatalities

In section 3.1, we have discussed and described several parameters of earthquake and tsunami that reasonably alleged of having influence on the emergence of fatalities (D&M). To analyze the relationship among these parameters we apply the statistical method, namely the Analysis of Covariance (ANCOVA). ANCOVA is a multivariate statistical method in which the dependent variable is a quantitative variable and the independent variables are a mixture of quantitative variables and qualitative variables (Lewis et al., 2004 and Wildt et al., 1978). Therefore, we will analyze the number of D&M for two epicenter locations while controlling parameters (covariates) of earthquakes and tsunamis by using the following model:

For earthquakes:

$$E(DM)_t = \beta_0 + \beta_1 Mag_t + \beta_2 Depth_t + \beta_3 Loc_t + \varepsilon_t\,, \qquad (3.1)$$

And for tsunamis:

$$E(DM)_t = \beta_0 + \beta_1 Mag_t + \beta_2 Depth_t + \beta_3 Height_t + \beta_4 Loc_t + \varepsilon_t\,, \qquad (3.2)$$

where:

DM = number of death and missing people (D&M),

Mag = magnitude of earthquake (Mw),

Depth = focal depth of hypocenter (kilometer),

Height = maximum water height (meter),

Loc = location of the epicenter, namely offshore/sea (o) and inland (m).

ε_t = error term.

A summary of the computational formulae associated with the analysis of covariance for the completely randomized design is presented in **Table 3.2**.

Table 3.2 **Analysis of Covariance for Completely Randomized Design.**

Source of Variation	Sum of Squares and Cross Products			Adjusted Sum of Squares	Degrees of Freedom	Adjusted Mean Square	Expected Mean Square	F-Ratio
	XX	XY	YY					
Group/ Treatment	--	--	--	$B_{YY(ADJ)}$	K-1	$\frac{B_{YY(ADJ)}}{K-1}$	$\sigma^2_{\varepsilon\mid\beta} + \frac{\sum N_I \sigma_I^2}{K-1}$	$\frac{MST_{(ADJ)}}{MSE_{(ADJ)}}$
Error	E_{XX}	E_{XY}	E_{YY}	$E_{YY(ADJ)}$	N-K-1	$\frac{E_{YY(ADJ)}}{N-K-1}$	$\sigma^2_{\varepsilon\mid\beta}$	
Total	T_{XX}	T_{XY}	T_{YY}	$T_{YY(ADJ)}$	N-2			

$$E_{XX} = \sum\sum\left(X_{ij} - \overline{X}_i\right)^2 \qquad T_{YY} = \sum\sum\left(Y_{ij} - \overline{Y}\right)^2$$

$$E_{XY} = \sum\sum\left(X_{ij} - \overline{X}_i\right)\left(Y_{ij} - \overline{Y}_i\right) \qquad E_{YY(adj)} = E_{YY} - E_{XY}^2/E_{XX}$$

$$E_{YY} = \sum\sum\left(Y_{ij} - \overline{Y}_i\right)^2 \qquad T_{YY(adj)} = T_{YY} - T_{XY}^2/T_{XX}$$

$$T_{XX} = \sum\sum\left(X_{ij} - \overline{X}\right)^2 \qquad B_{YY(adj)} = T_{YY(adj)} - E_{YY(adj)}$$

$$T_{XY} = \sum\sum\left(X_{ij} - \overline{X}\right)\left(Y_{ij} - \overline{Y}\right) \qquad b_w = E_{XY}/E_{XX}$$

The summary results of the regression model using ANCOVA for earthquakes and tsunamis are presented in **Table 3.3** and **Table 3.4**, respectively. Note that all the models as a whole for both earthquakes and tsunamis in Japan and Indonesia are statistically significant. However, not every explanatory variable is statistically significant. This evidence, in fact, reveals some characteristics of each natural disaster in each country. In **Table 3.3**, the earthquake magnitude has a significant effect on the number of D&M in Japan and Indonesia. However, only in Japan does the location of epicenter have a significant effect on D&M.

In addition, parameter values of magnitude for Japan is greater than Indonesia, this implies that in average the number of casualties caused by earthquakes in Japan is higher than in Indonesia. One possible cause is the population density in Japan is higher than in Indonesia, for example, the population density in 2010 in Japan is 337 people per km^2 and in Indonesia is 124 people per km^2. Meanwhile, the negative sign of the location variable implies that the closer the location of the epicenter to the mainland, the greater the likelihood of casualties inflicted.

Table 3.3 **Summary results of the regression model for earthquakes.**

Dependent Variable: DM

Source	Japan					Indonesia				
	Type III Sum of Squares	DF	Mean Square	F value	Pr > F	Type III Sum of Squares	DF	Mean Square	F value	Pr > F
Model	8304770.627	3	2768256.876	7.348	0.000	373058.734	3	124352.911	4.645	0.004
Error	64424558.230	171	376751.803			5059856.303	189	26771.726		
Total	72729328.857	174				5745406.000	193			
	R-Squared = 0.114 (Adjusted R-Sq = 0.099)					R-Squared = 0.069 (Adjusted R-Sq = 0.054)				

Parameter		Japan				Indonesia			
		Estimate	T for H_0: Parameter=0	Pr > |T|	Std Error of Estimate	Estimate	T for H_0: Parameter=0	Pr > |T|	Std Error of Estimate
Intercept		-873.445*	-2.163	0.032	403.768	-257.180	-3.017	0.003	85.231
Mag		206.117***	3.309	0.001	62.291	48.518***	3.673	0.000	13.208
Depth		-1.224	-1.681	0.095	0.728	-0.180	-1.096	0.275	0.164
Loc	o	-475.840*	-4.042	0.000	117.712	-32.873	-1.246	0.214	26.377
	m	0	.	.	.	0	.	.	.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.4 **Summary results of the regression model for tsunamis.**

Dependent Variable: DM

Source	**Japan**					**Indonesia**				
	Type III Sum of Squares	**DF**	**Mean Square**	**F value**	**Pr > F**	**Type III Sum of Squares**	**DF**	**Mean Square**	**F value**	**Pr > F**
Model	4858089.682	4	1214522.421	12.504	0.000	4021051.096	4	1005262.77	43.830	0.000
Error	11752457.747	121	97127.750			940364.557	41	22935.721		
Total	17135126.000	126				5647056.000	46			
	R-Squared = 0.292 (Adjusted R-Sq = 0.269)					R-Squared = 0.810 (Adjusted R-Sq = 0.792)				

Parameter		**Japan**				**Indonesia**			
		Estimate	**T for H_0: Parameter=0**	**Pr > |T|**	**Std Error of Estimate**	**Estimate**	**T for H_0: Parameter=0**	**Pr > |T|**	**Std Error of Estimate**
Intercept		-850.165	-2.290	0.024	371.224	305.324	1.245	0.220	245.175
Mag		116.971*	2.267	0.025	51.592	-49.382	-1.463	0.151	33.746
Depth		-0.978	-0.622	0.535	1.573	-0.290	-0.904	0.371	0.321
Height		27.114***	5.178	0.000	5.236	56.553***	12.697	0.000	4.454
Loc	o	82.764	0.579	0.563	142.829	-31.691	-0.518	0.607	61.131
	m	0	.	.	.	0	.	.	.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Furthermore, **Table 3.4** shows that the maximum water height is the most important factor in a tsunami event, which can claim number of D&M. This variable is highly statistically significant. Although tsunami is more frequent in Japan than Indonesia, however the D&M caused by tsunami in Indonesia tend to increase, therefore, both governments should take more precautionary efforts in order to mitigate the number of victims and damages/losses due to tsunami events. Moreover, the magnitude of earthquakes also plays a significant role in causing D&M.

This evidence could be a warning for those people who live near the shore or coastal areas, since they would be the first victims to be stricken if there is a tsunami. Based on the tsunami data from GHTD, the maximum water height of the tsunami when reached the shore in Aceh and in Tohoku were 50.9 m and 38.9 m, respectively. Therefore, there should be some rules related with the safe distance to build residences from the shoreline, or if there are some people who live in areas with a supposedly dangerous tsunami threat, the government should relocate them to some other safe places and/or build tsunami walls.

3.3 Recovery policies for the 2004 Aceh tsunami and the 2011 Tohoku tsunami

The recovery process involves the actions taken in the long term after the immediate impact of the disaster has passed to stabilize the community and restore some semblance of normalcy (Altay and Green, 2006). Generally, the recovery phase is divided into two phases, namely rehabilitation and reconstruction. Rehabilitation is any activity with the objective to restore normalcy in conditions caused by the disaster. Reconstruction defines as the repair and construction of a property undertaken after a disaster. The common principle/slogan for to the recovery process is "building back better." The recovery process covers all sectors affected by the disaster, and one of the sectors that get the top priority to be immediately restored is the agricultural sector, given that agricultural affected lands need to be quickly rehabilitated to restore the production capacity of farmers and ensure food security (FAO, 2005). In addition, in Aceh, on a sectoral basis, outside of oil and gas, agriculture has the largest share of Aceh GDP at 32%. Almost half the people in Aceh (47.6%) are working in agriculture sector (Bappenas, 2005). Likewise, based on the data taken from the Statistical Yearbook (various year) issued by the Ministry of Agriculture, Forestry, and Fisheries (MAFF) of Japan, the economy of most prefectures in Tōhoku Region remains dominated by traditional industries, such as agriculture, fishing, and forestry.

The Japan's agriculture sector suffered $30 billion in losses from the March earthquake and deadly tsunami, which deluged crops, and radiation releases from the Fukushima Daiichi plant. According to the Japanese government 21,476 hectares of farmland was inundated by the tsunami in the Tohoku and Kanto regions, Miyagi Prefecture suffered the worst damage, with 14,341 hectares of farmland in five cities flooded by seawater—more than 50 percent of the total farmland in those cities. Places where tsunami waters receded quickly suffering relatively minor damage to the soil.

Whilst in Aceh Province, the damage of farmland area was estimated 61,816 hectares, which scattered in 11 districts out of 21 districts. Aceh Besar suffered the most extensive damage to agricultural land, namely 16,320 hectares, followed by Aceh Jaya with 11,868 hectares. Places were farmland remained flooded for some time and salt was deposited in the soil into the suffered significant soil damage that would require at least a year to restore. **Table 3.5** describes the estimated areas of agricultural land damaged due to the 2004 Aceh tsunami and the 2011 Tohoku tsunami.

Table 3.5 **Estimated areas of agricultural land damaged due to Aceh and Tohoku tsunami.**

The 2004 Aceh Tsunami, Indonesia [a]				**The 2011 Tohoku Tsunami, Japan [b]**			
District	**Harvested Area (Ha)**	**Damaged Area**		**Prefecture**	**Harvested Area (Ha)**	**Damaged Area**	
		Ha	**%**			**Ha**	**%**
Simuelue	8,456	3,489	41.26	Aomori	46,900	77	0.16
East Aceh	30,477	2,119	6.95	Iwate	54,500	725	1.33
West Aceh	17,079	4,084	23.91	Miyagi	66,400	14,341	21.60
Aceh Besar	37,334	16,320	43.71	Fukushima	64,400	5,462	8.48
Pidie	40,953	5,932	14.48	Ibaraki	77,100	208	0.27
Bireuen	40,675	2,685	6.60	Chiba	60,500	663	1.10
North Aceh	43,639	1,836	4.21	**Total**	**369,800**	**21,476**	**5.81**
Southwest Aceh	22,253	7,838	35.22				
Nagan Raya	29,506	5,520	18.71				
Aceh Jaya	13,342	11,868	88.95				
Banda Aceh	174	125	71.84				
Total	**283,888**	**61,816**	**21.77**				

Source:
[a] BPS, Statistics of Indonesia and Rehabilitation and Reconstruction Agency (BRR) for Aceh.
[b] Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF).

In Aceh Province, in order for the rehabilitation and reconstruction process can run smoothly and can realize better condition than before the disaster, the Indonesian Government has mandated the Rehabilitation and Reconstruction Agency (BRR) to coordinate and be responsible for the recovery process in Aceh. The BRR's headquarter was in Banda Aceh city, capital of Aceh. The BRR commenced operations in May 2005 until 2009. Until the closure of BRR in April 2009, many activities of rehabilitation and reconstruction have been completed, including in the agricultural sector. **Figure 3.9** portrays one of the achievements of recovery in the agricultural sector by district in Aceh Province. While **Figure 3.10** shows the productivity progress of paddy plants in Aceh Province.

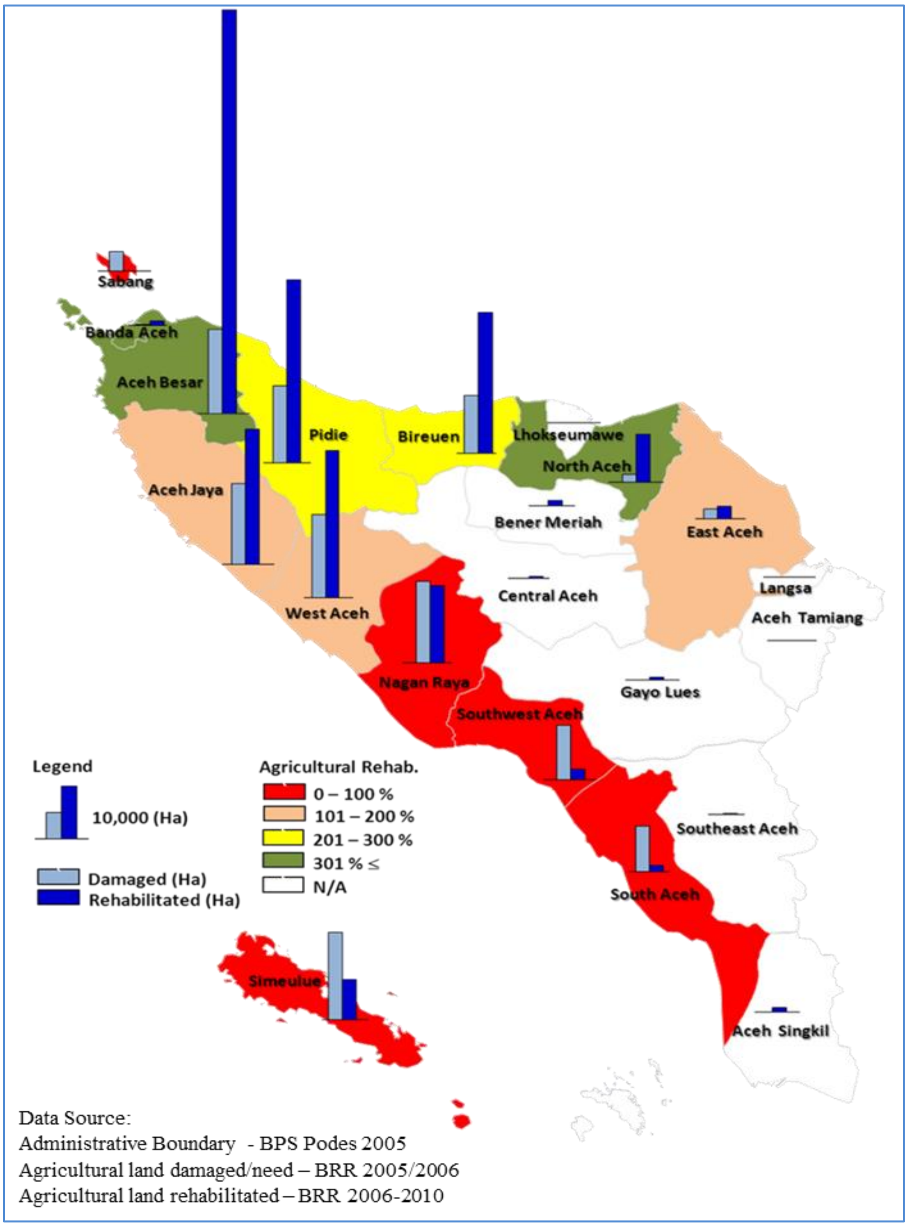


Figure 3.9 **Agricultural land rehabilitation in Aceh Province by district.**

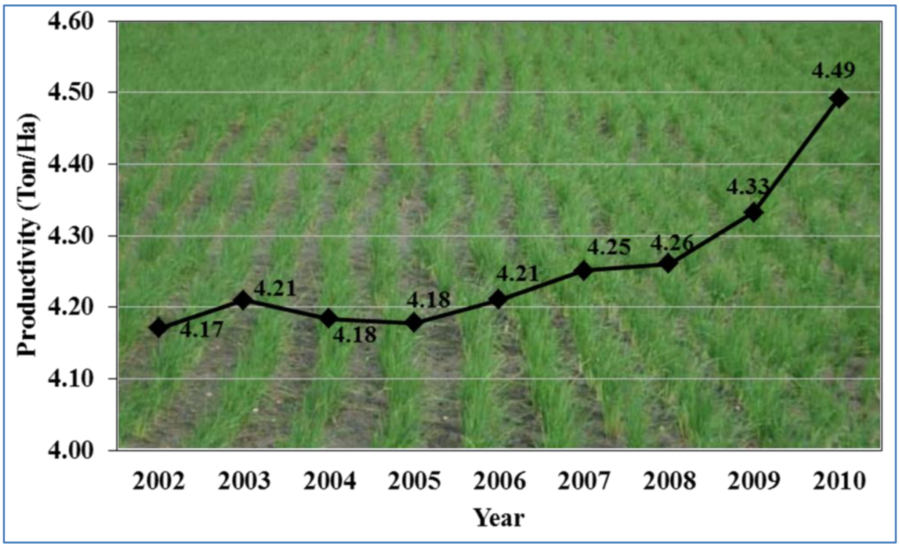


Figure 3.10 **Productivity (Ton/Ha) of paddy plants in Aceh Province, 2000-2010.**

Figure 3.11 displays the production of paddy in the Tohoku region from one year before and one year after the disaster occurred. In 2011, the year when the disaster occurred, all prefectures, except Akita, experienced decreasing in production of paddy. Fukushima experienced the largest decreasing in paddy production, followed by Miyagi, Iwate, Yamagata, and Aomori. From prefectures that experienced decreasing in paddy production, Aomori has the fastest recovery in production of paddy, namely the production of paddy in 2012 already surpass the production in 2010. In addition, Fukushima has the slowest recovery in paddy production. One of the reasons is beside the earthquake and tsunami, Fukushima also suffered from the nuclear power plant accident. In which, have made many people to leave their hometown and for the health safety reason the production of paddy also has been deliberately reduced.

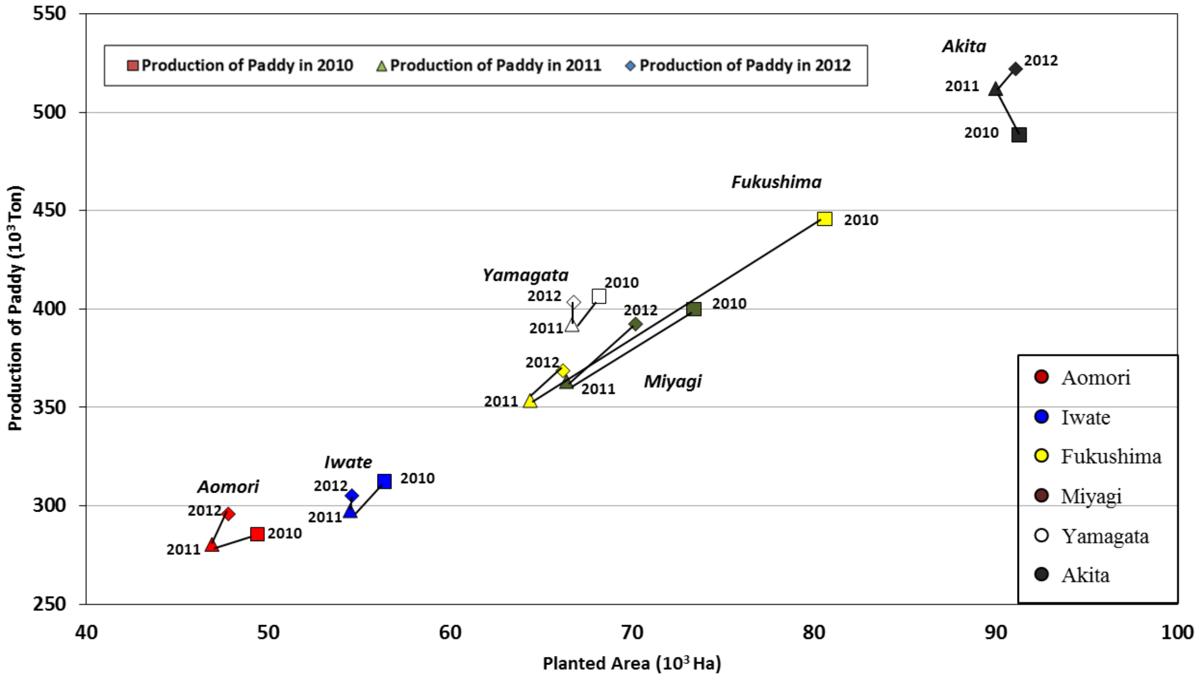


Figure 3.11 **Production of paddy in Tohoku Region.**

The Great East Japan Earthquake, which occurred on March 11, 2011, was a natural catastrophe that not only devastated an extremely large area of eastern Japan together with following massive tsunamis, but also compounded with the nuclear power plant accident, making them as one of the most expensive compound disasters ever recorded in the history. Accordingly, the Japanese Government set up an advisory panel of intellectual figures under the name of the Reconstruction Design Council in Response to the Great East Japan Earthquake and its Study Group for engaging in broad discussions of a framework for formulating governmental reconstruction guidelines. The “Seven Principles for the Reconstruction Framework” were formulated as a set of recognitions shared by all its members in the Reconstruction Design Council at its 4th session held on May 11, 2011 ahead of the issuance of its report of recommendations and serve as the guiding philosophy in the report of the Council.

There have been significant progresses made towards rebuilding and revitalizing areas affected by the Great East Japan Earthquake disaster. Nevertheless, in the disaster-hit areas and elsewhere in the country, many people's lives are still greatly inconvenienced because of the damage caused. This includes those who are still unable to return to their homes even now because of the nuclear accident. In the agricultural sector, the restoration plan for farming is on schedule, aiming to have approximately 90% of farmland back in operation by 2014, while the fisheries sector is also on its way to a full-scale recovery. There have also been numerous initiatives that support revitalization of local economies through public-private partnerships, many of which are leveraging advanced technologies such as information and communication technology (ICT) and clean energy, as well as high-tech agricultural initiatives.

CHAPTER IV

MEASURING THE IMPACTS OF THE 2011 GREAT EAST JAPAN EARTHQUAKE AND EVALUATING THE RECOVERY PERFORMANCE

4.1 The 2011 Great East Japan Earthquake (GEJE)

On March 11, 2011 at 14:46 JST a powerful earthquake with magnitude 9 Mw hit the northeastern part of Japan. The March 2011 disaster, also known as the 2011 Great East Japan Earthquake (GEJE), caused unprecedented damage in the Tohoku region and resulted in a period of crisis that affected the entire nation (Parwanto and Oyama, 2013). The epicenter of the earthquake was approximately 70 kilometers east of the Oshika Peninsula of Tohoku and the hypocenter at an underwater depth of approximately 30 km. This earthquake then triggered a powerful tsunami that devastated cities, towns, and villages along a broad swath of the Pacific coast of the Tohoku Region, causing vast human and material damage. The National Police Agency of Japan, as of May 9, 2014, had confirmed that the number of deaths had reached 15,886, with an additional 2,640 missing and 6,148 injured (NPA, 2014). There were also 303,571 displaced people living in evacuation centers nearby and 127,382 buildings totally collapsed. The disaster also caused nuclear accidents at the Fukushima Daiichi Nuclear Power Plant complex. The World Bank estimated the economic cost this compound disaster fell between 122 billion US$ and 235 billion US$, or about 2.5% - 4% of Japan's gross domestic product (GDP) (World Bank, 2011).

When this compound disaster hit Japan, Japan was still recovering from the Financial Crisis of 2007-2008, also known as the 2008 Global Financial Crisis (GFC). Before the 2008 GFC that began in the U.S. affected the economy of Japan and several other countries in the world, Japan had enjoyed a stable economy during previous decade, namely, average growth at about 0.1% annually from 2000-2007[13]. The 2008 financial crisis caused a contraction of the Japanese economy of about 2.5% from 2007 to 2008. The largest decline was experienced by the industrial sector (-4.9%), followed by the agriculture sector (-2.6%) and the services sector (-1.6%). However, it turns out that the effects of the financial crisis worsened in 2009, in which the Japanese economy fell by 5.9% from 2008. The performance of the industry sector declined by 11%, followed by the agriculture sector (-4.6%) and the services sector (-4%). By 2010, the Japanese economy had begun to recover with growth of 2.4%, which far exceeded the average growth over the last decade. The highest growth was experienced by the industrial sector (8.3%), followed by agriculture (4%) and the services sector (0.3%).

Japan's economy, the world's third largest, slid back into recession after the devastation caused by the 2011 GEJE. As argued by Noy (2009), Strobl (2012), and Porfiriev (2012), natural disasters have a statistically adverse impact on the macro-economy in the short run and increase the vulnerability of the global economy. The 2011 GEJE caused a decrease in Japan's GDP (at the 2005 constant price) of about 2.2%, namely, from 4.8 trillion US$ in 2010 to 4.7 trillion US$ in 2011. This decrease was due to a decline in the industrial sector of -7.1%, followed by the agricultural sector (-3.6%) and the services sector (-0.2%). Thus, the first two sectors, industrial and agricultural, are the sectors that most suffered due to the disaster. The high decline in the agricultural sector was presumably due to the damage to and loss of deluged crops, damage to facilities, and radiation released from the Fukushima Daiichi plant. Meanwhile, the industrial sector, including the manufacturing sector, also declined, which was alleged to be as the result of destruction of parts factories in northeastern Japan, which in turn caused severe supply shortages for many manufacturers.

[13] Based on the data taken from the National Accounts of Japan for year 2000 - 2012, issued by the Cabinet Office of Japan.

According to the Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF), the amount of damage and losses to the agriculture, forestry, and fisheries sectors caused by the 2011 disasters was estimated at 238 billion US$. MAFF also estimated about 23,600 hectares of farmland were inundated by the tsunami in the Tohoku and Kanto regions, Miyagi Prefectures suffered the worst damage, with 15,002 hectares of farmland in five cities flooded by seawater – more than 50 percent of the total farmland in those cities.

Meanwhile, in the industrial sector, according to the Tohoku Bureau of Economy, Trade and Industry, the natural disasters forced auto firms and other manufacturers in Tohoku region to shut down production, and operations have taken a long time to restart. Toyota and Honda are two examples of giant automotive companies that had to halt their productions due to these natural disasters. As their productions in Tohoku region are mainly affiliated with vehicle body manufacturers, this temporary discontinuation forced other related plants to suspend production, for example, production of hybrid vehicles at the Tsutsumi Plant in Aichi and at Toyota Motor Kyushu in Fukuoka. Globally, the impact of supply shortages of spare parts not only affected production in Japan. In North America, due to the lack of spare parts, Toyota had to announce the suspension of production of all vehicles, engines, and components at its factories. Due to the same problem, Ford had to idle its automotive plants in Genk, Belgium. Ford also had to stop taking new orders for some car body colors because of the shortage of certain pigments sourced from Japan.

From the descriptions, naturally, the impact of the 2011 GEJE has sharply delineated the critical role played by the agriculture and industrial sectors. The impact has reduced agricultural production and disrupted the supply chains of manufacturing products, namely electronic products and car parts not only domestically but also globally. Therefore, it will be of great interest to study how to get these agricultural producers and internationally competitive parts and materials manufacturers back on their feet as part of the recovery process of the Tohoku region as well as an important aspect of maintaining Japan's industrial competitiveness.

Three years have passed, and according to the Ministry of Foreign Affairs of Japan, Japan has received, so far, assistance from 163 countries and 43 international organizations. The detail of the assistance from overseas for the recovery is reported in **Appendix A**. Thus, it is an appropriate time to reflect on the progress made to date, approaching the reconstruction undertaken after natural disasters as an opportunity for development (Lyons, 2009). Reconstruction and revitalization of the economies, communities, and livelihoods impacted by this disaster remains a national priority. This Chapter IV will elaborate information and lessons on recovery processes following the 2011 GEJE. Its main objectives are to investigate the damaging impact of the 2011 GEJE and the performance of restoration and reconstruction in the agricultural and manufacturing sectors. As the contribution of the manufacturing sector to the industrial sector is, on average, around 70%, so in this Chapter IV we will focus on the recovery of the manufacturing sector. In addition, the Tohoku region was the most severely damaged region, therefore in some parts of the discussions we will focus on this region.

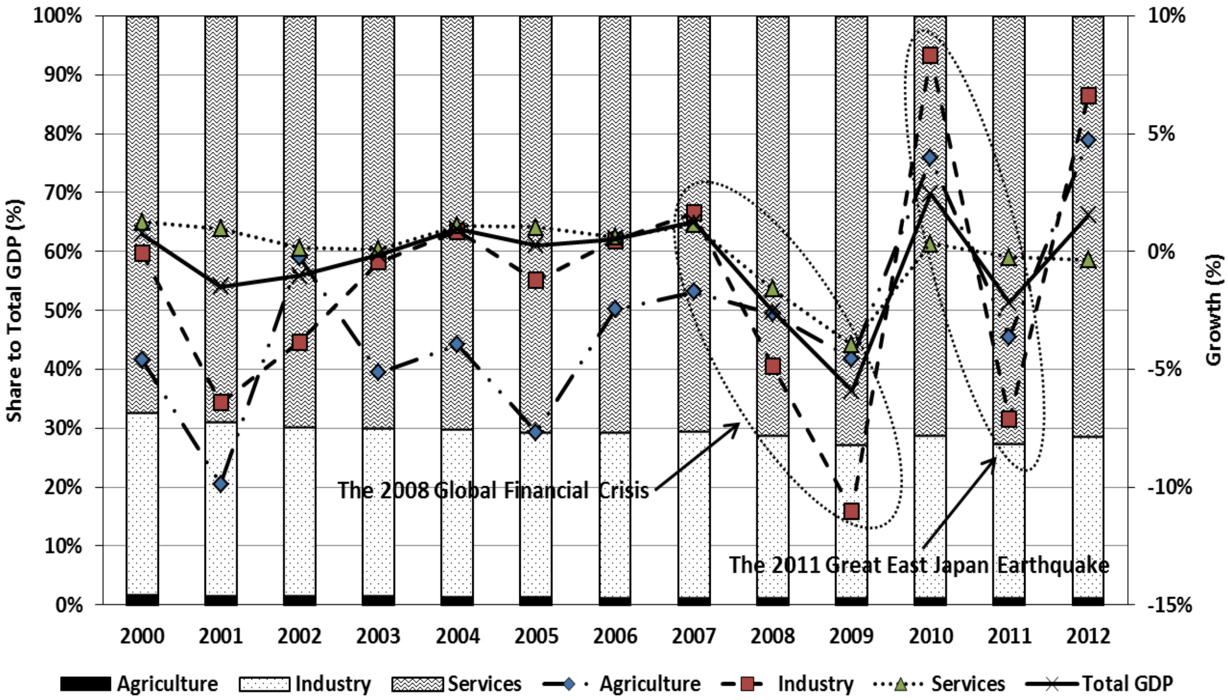
4.2 Economic overview before and after the 2011 GEJE

4.2.1 National and regional economic overview

As one of the developed countries, which countries have post-industrial economies, meaning the service sector provides more wealth than the industrial sector; Japan has also relied on her economy on the services sector[14]. From **Figure 4.1**, on

[14] Statistics Bureau of Ministry of Internal Affairs and Communications. Japan Statistical Yearbook (various edition).

average, from 2000 to 2010 the services sector share of the total GDP before the 2011 GEJE was about 70.3%, followed by the industry sector (28.4%) and the agriculture sector (1.3%). In the same period, on average, the Japanese economy registered a minus 0.4%, with the highest growth in 2010 (2.4%), two years after the 2008 Global Financial Crisis (GFC) hit Japan.



Data source: Japan Statistical Yearbook (2000-2012)

Figure 4.1 **Share and growth of GDP by economic activity, 2000-2012**

At the beginning of 2008, the Japanese economy was at a standstill in its path to recovery as private consumption, investments in plants and equipment, and production fell flat. This occurred against the backdrop of soaring crude oil and raw material prices and repercussions from the American subprime mortgage loan problems that, since mid-2007, rapidly clouded future prospects for the world economy. In addition, the bankruptcy of the major American securities firm Lehman Brothers in September 2008 (the "Lehman shock") led to a serious financial crisis in Europe and the USA (Dumontaux and Adrian, 2013 and Aragon and Philip, 2012). Japan was also affected by the yen's rise and the sudden economic contraction in the U.S.A. and other countries.

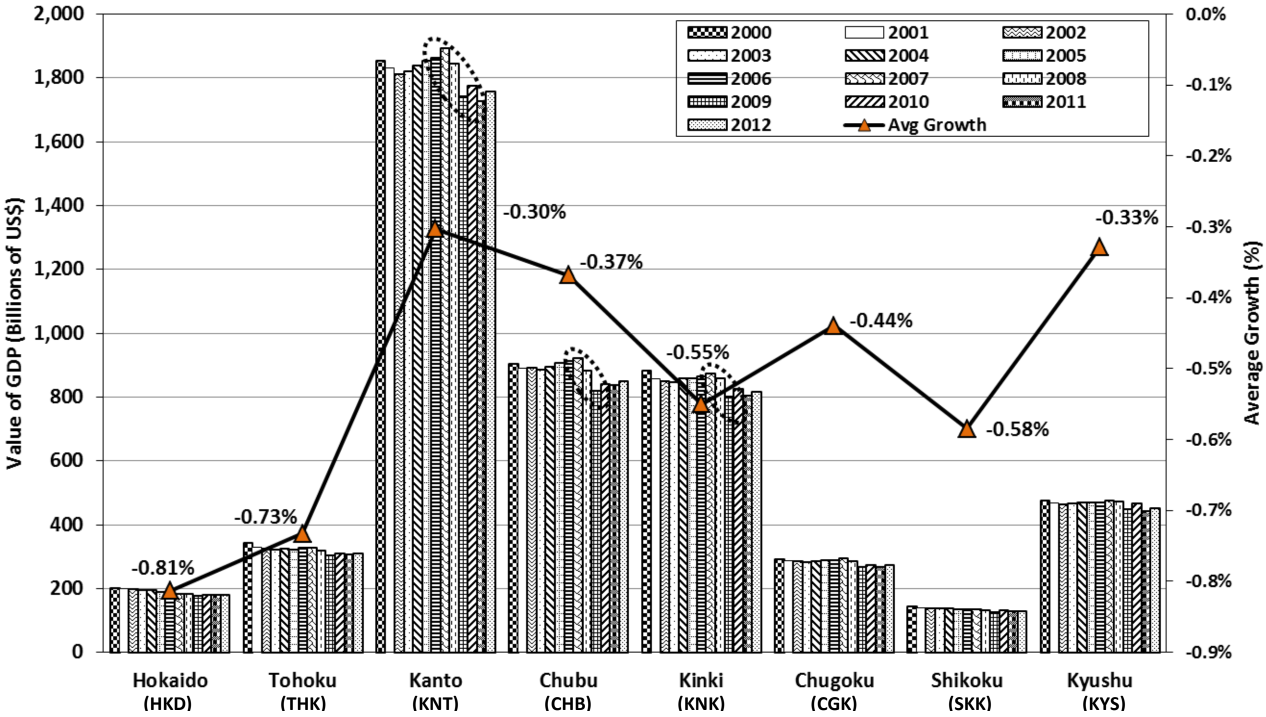
In the period of 2000-2011, the economy of Japan had actually undergone two major disruptions, namely the 2008 GFC and the 2011 GEJE. The first disruption, which lasted for two years, induced contractions in the Japanese economy 2.5% and 5.9% in 2008 and 2009, respectively, and the highest decrease was experienced by the industrial sector at 11% in 2009. The decline in the growth of the Japanese economy that occurred in 2009 was the largest decline over the last 50 years. After suffering from the 2008 GFC for two years, the economy of Japan started to recover in 2010. Unfortunately, when the Japanese economy had just started to recover, another disruption occurred after the 2011 GEJE. The disaster caused Japan's economy to contract by 2.2%. As in 2009, the sector most severely hit by the disaster was the industrial sector, in which growth declined by 7.1%. Based on these two experiences, it seems that the industrial sector is relatively prone toward contractions in growth, whereas the agricultural sector and the service sector are less prone. This should be a concern for the Government of Japan in the future, given that workers employed in the industrial sector account for about 28% of the entire workforce.

Japan has 47 prefectures, which are often grouped into eight regions: Hokkaido, Tohoku, Kanto, Chubu, Kinki, Chugoku, Shikoku, and Kyushu (including Okinawa). According to the Disaster Relief Act which is applied to regions (i.e., cities, towns, and villages), there are nine affected prefectures with total of 198 affected regions, including Aomori (2 regions), Iwate (34 regions), Miyagi (39 regions), Fukushima (59 regions), Ibaraki (37 regions), Tochigi (15 regions), Chiba (8 regions), Niigata (3 regions), and Nagano (1 region). Among these affected prefectures, the first four prefectures, namely the prefectures in Tohoku region have been the most affected by the 2011 GEJE.

In Hokkaido, agriculture and other primary industries play a large role in the economy as it has nearly one fourth of Japan's total arable land. It ranks first in the nation in the production of a host of agricultural products. The largest city on Hokkaido is its capital, Sapporo. The Tohoku area is primarily agricultural: 65% of cultivated land is rice paddy fields, which account for almost a quarter of all the paddy fields throughout the country. Sendai is the largest city. The Kanto region, which includes such key cities as Tokyo, Yokohama, Kawasaki, Saitama, and Chiba, is the most populous region of Japan. The hub of the region - the Tokyo-Yokohama district - is the core of Japan’s commerce, services, and industry. Tokyo is the capital of Japan. It is home to most large domestic corporations, foreign companies, and the head offices of the mass media. Tokyo is also a center of education. The Chubu region has some of Japan’s longest rivers and one of the largest rice-producing areas, located along the Sea of Japan. It has three industrial areas: the Chukyo Industrial Zone, which is home to the main facility of Toyota Motors; the Tokai Industrial Region, where Yamaha is based; and the Hokuriku Industrial Region. The Kinki region is Japan’s second most important area in terms of industry. Kyoto, once the capital of Japan and the residence of emperors from 794 to 1868, is located in this region. The Chugoku region is mountainous with many small basins and coastal plains. The Inland Sea coast is an important area of industry and commerce. The Shikoku region has high and steep mountains that serve as a limit to farming and habitation, and there is little large-scale industry. In the Kyushu region, agriculture, stock farming, hog raising, and fishery all flourish. The Kita Kyushu Industrial Zone contains a concentration of heavy and chemical industries. In Okinawa Prefecture tourism is the main industry.

During the 2000-2012 period, Kanto had the highest regional GDP (RGDP) and average share of Japan's GDP (36.9%), followed by Chubu (17.8%), Kinki (17.2%), Kyushu (9.4%), Tohoku (6.5%), Chugoku (5.7%), Hokkaido (3.8%), and Shikoku (2.7%). **Figure 4.2** shows the value of GDP by region and average growth during the

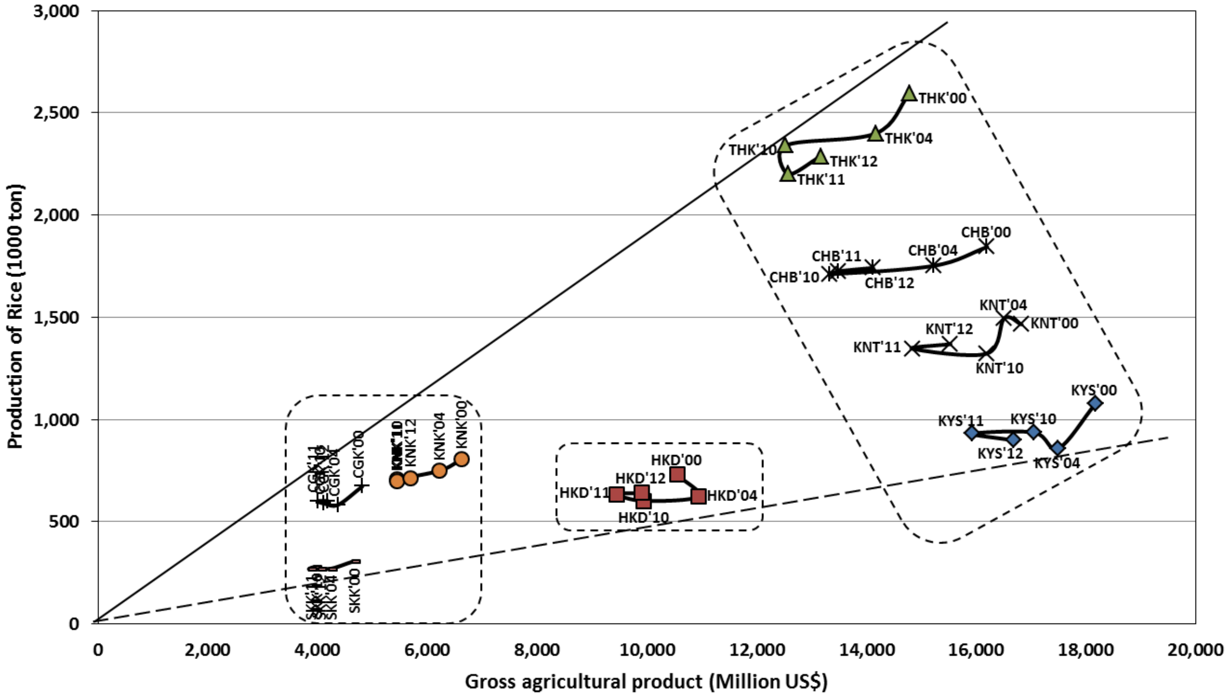
2000-2010 period. In terms of the value of GDP growth during this period, it appears that the entire region had an average negative growth, with the Kanto recording the largest growth (-0.3%) and Hokkaido having the smallest at -0.81%. **Figure 4.2** also shows the three regions which were most affected by the 2008 GFC, namely, Kanto, Chubu, and Kinki, regions with the highest share of RGDP.



Data source: Japan Statistical Yearbook (2000-2012)

Figure 4.2. **Value of GDP by regions and average growth (percentage), 2000-2012**

Figure 4.3 presents the relationship between the production of rice and gross agricultural products (GAP) in each region from 2000 to 2012. In **Figure 4.3**, based on the production of rice and the value of GAP, we can separate the regions into three groups. The first group is regions that have high shares of rice production and GAP (more than 10%), which comprise of the four regions of Tohoku, Chubu, Kanto, and Kyushu. Among these regions, Tohoku has the highest share of rice production but has the lowest share of GAP, whereas Kyushu has the lowest share of rice production but the highest share of GAP. In the second group, there is only the Hokkaido region, which has GAP in excess 10% but rice production of less than 10%. The third group is regions with low shares (less than 10%) of rice production and GAP; these include Chugoku, Kinki, and Shikoku, with Shikoku having the lowest rice production and GAP.

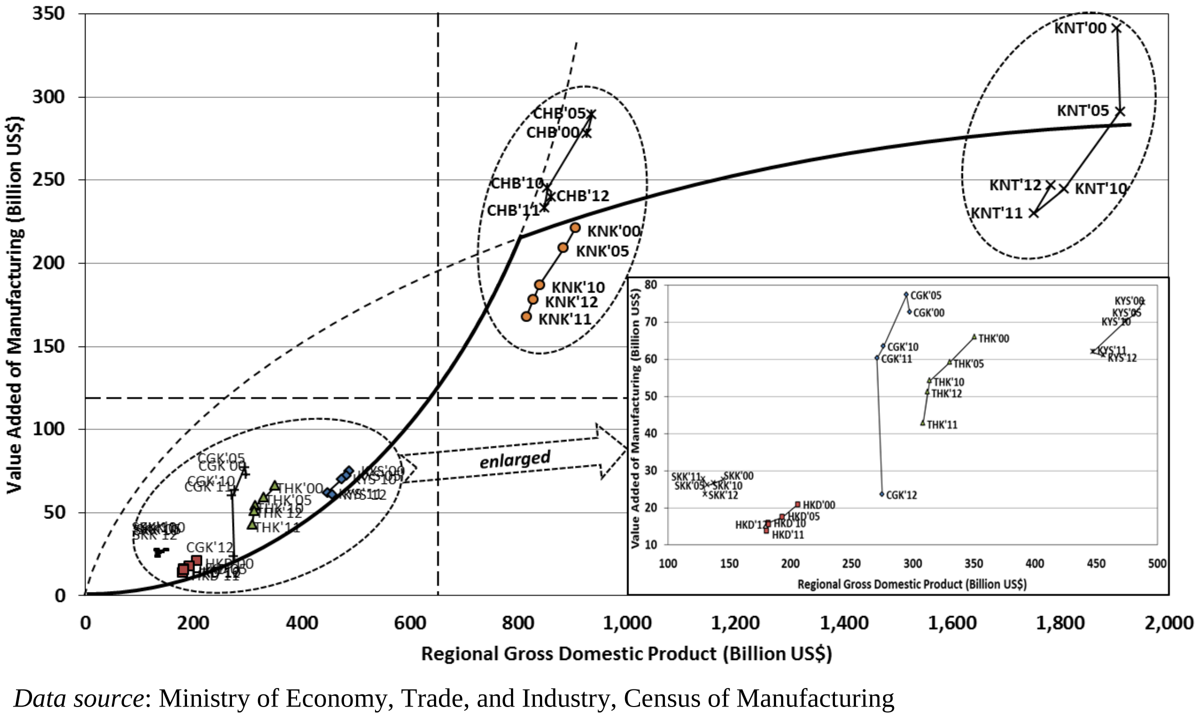


Data source: Japan Statistical Yearbook (2000-2012)

Figure 4.3 **Gross agricultural product and production of rice, 2000-2012**

Figure 4.4 shows the changes in value added by manufacturing (VAM) and regional GDP (RGDP) from 2000 to 2012 by region. VAM is obtained from the Manufacturing Census conducted by the Ministry of Economy, Trade, and Industry (METI). Here, we can classify the regions into three groups, with regions with high RGDP and high VAM as the first group, regions with middle RGDP and high VAM as the second group, and regions with low RGDP and low VAM as the third group. In addition, in **Figure 4.4** we can see the enlarged third group in order to see more details. **Figure 4.4** also shows the share of manufacturing sector compared to the total economic activity in each region. During 2000-2012, Kanto is in the first group with an average share of 14.73%; Chubu and Kinki are in the second group with average shares of 29.01% and 22.49%, respectively, while the rest of the regions form the third group, with Hokkaido having the smallest share (8.81%). Thus, during 2000-2012, Chubu had the highest share of VAM to RGDP, which implies that although Kanto has the highest VAM, apparently, manufacturing is not the leading sector of the economy in Kanto, while with an average share of almost 30%, manufacturing is the leading sector in Chubu as it has 3 industrial zones, namely: the Chukyo Industrial Zone, the Tokai Industrial Region, and the Hokuriku Industrial Region.

Furthermore, the relationship model between VAM and RGDP implies that up to a certain value of RGDP, the economy of a region will be dependent on industrial manufacturing. However, after exceeding a particular value of RGDP, the economy of the region will be less dependent on industrial manufacturing and more dependent on the services and commerce sectors, such as is true for the Kanto region. Therefore, in the future, the Kinki and Chubu regions will more likely to have similar economic structures as that of the Kanto region, in which the economy is more dependent on the services and commerce sectors.

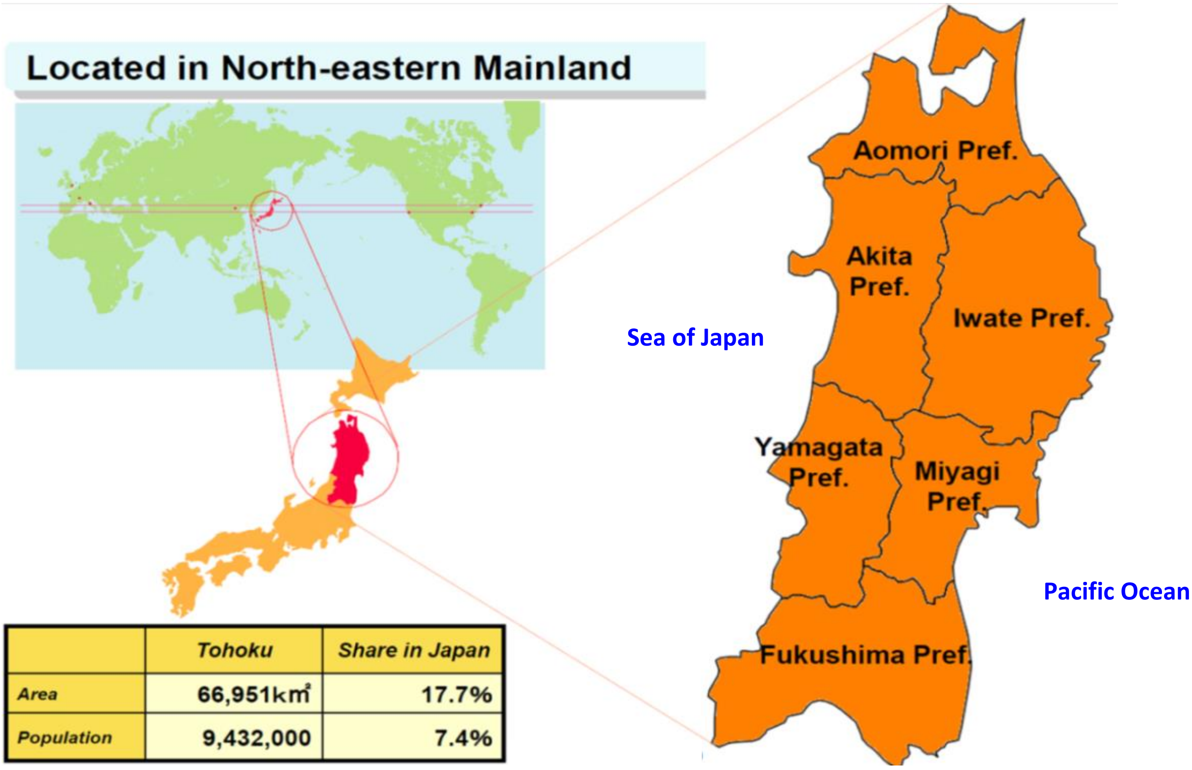


Data source: Ministry of Economy, Trade, and Industry, Census of Manufacturing

Figure 4.4 **Regional GDP and value added of manufacturing, 2000-2012**

4.2.2 Economic overview of Tohoku Region

The Tohoku region is located in the northeastern part of Honshu island, the largest island in Japan. Tohoku was the region most affected by the 2011 GEJE, with four of the six Tohoku prefectures suffering major damage: Aomori, Iwate, Miyagi, and Fukushima. Tohoku, like most of Japan, is hilly or mountainous; meaning much of the region's population is concentrated in the coastal lowlands. According to the Census of Population in 2010, the area of Tohoku region is about 66,889 km^2, or 17.7% of Japan's total area. The population is 9,335,636, or 7.4 % of Japan's total population, and the population density is about 140/km^2. **Figure 4.5** shows a map of the Tohoku region.



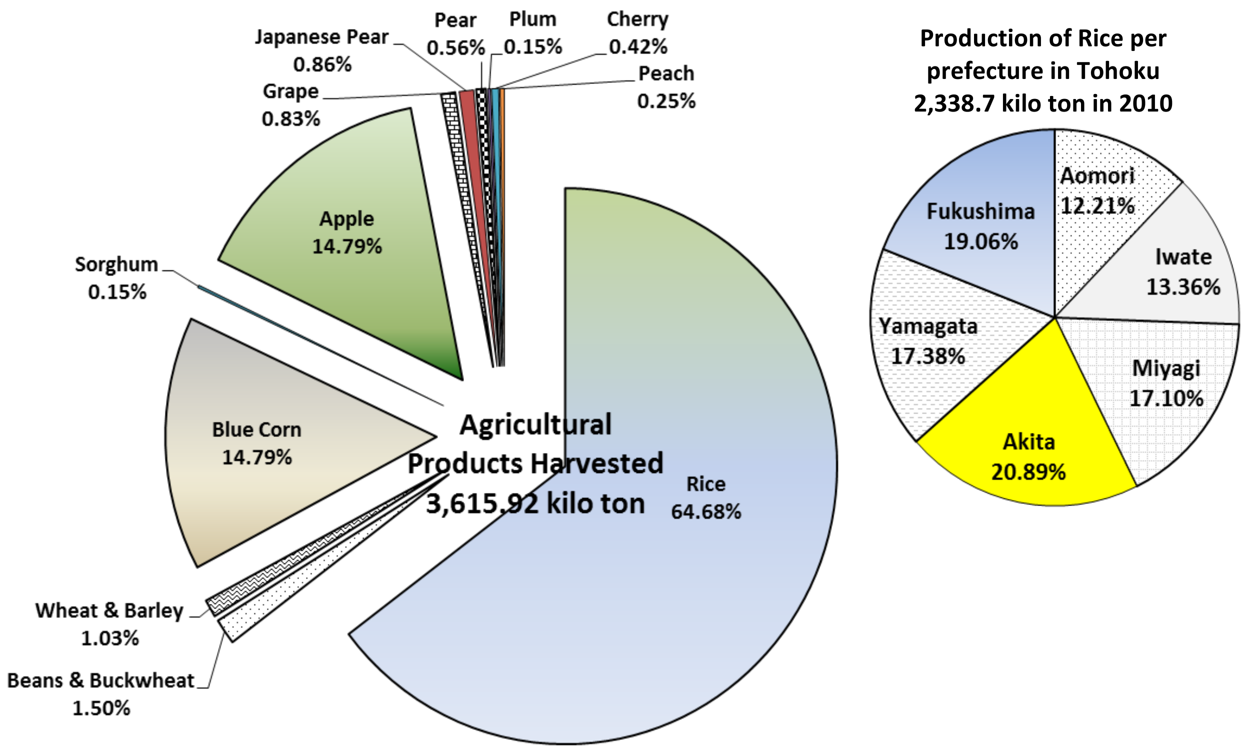
Source: Japanese Ministry of Foreign Affairs (MOFA): Web of Japan

Figure 4.5 **Map of the Tohoku region**

In the Tohoku region, during the period 2000-2012, Miyagi had the highest RGDP value with an average value of the total share of Japan's GDP was 25.4%; this was followed by Fukushima (23.4%), Iwate (13.8%), Aomori (13.7%), Yamagata (12.2%), and Akita (11.6%). Therefore, we can estimate that the affected prefectures in

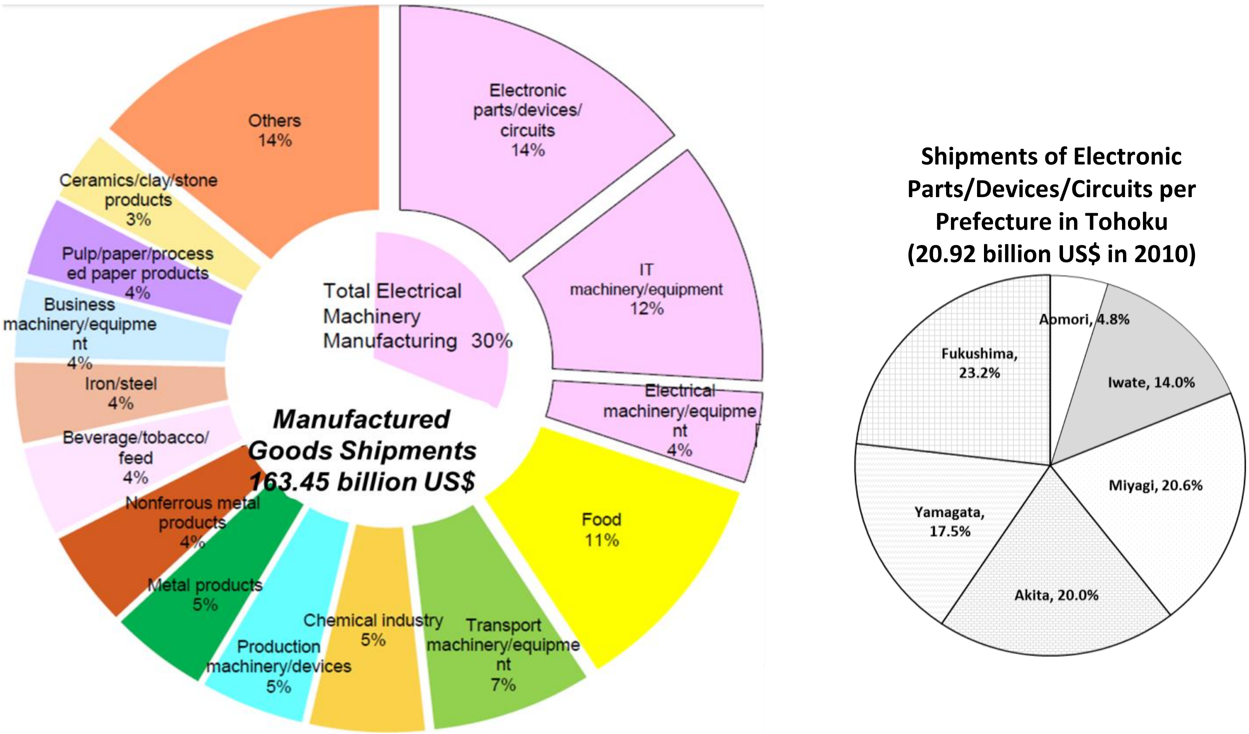
Tohoku accounted for about 76.3% of the average total RGDP of Tohoku. In terms of the value of RGDP growth during this period, it appears that all the prefectures experienced an average negative growth, with the highest value in Miyagi (-0.72%) and the lowest value in Iwate (-1.37%). In Tohoku, Miyagi and Fukushima were the prefectures most affected by the 2008 GFC.

Figure 4.6 shows the production of various commodities in the Tohoku region in 2010, among which paddy/rice is a mainstay commodity with contribution of 64.68%; followed by the production of apple and corn, which each commodity has contributed approximately 14.79% of the total agricultural production in Tohoku region. However, because of the climate, which is harsher than in any other parts of Honshu, only one crop can be grown each year, every prefecture in Tohoku region has high rice production of more than 280 kilotons for a total of about 2,338.7 kilotons in 2010, where Akita Prefecture has the highest rice production, followed by Fukushima Prefecture.



Data source: MAFF, World Census of Agriculture and Forestry (2010)

Figure 4.6 **Share of agricultural products harvested by commodities commodity and share of production of rice per prefecture in the Tohoku Region, 2010.**



Data source: METI, Census of Manufacturing (2010)

Figure 4.7 **Share of manufactured goods shipments by industry and share of shipments of electronic parts/devices/circuits per prefecture in the Tohoku, 2010.**

Figure 4.7 describes the share of manufactured goods shipments by industry and the share of shipments of electronic parts/devices/circuits per prefecture in the Tohoku region. The manufacturing of electrical machinery includes electronic parts, devices, and circuits, IT machinery and equipment, electrical machinery and equipment. METI estimated that shipments of electronic parts/devices/circuits from the Tohoku region accounted for about 20.92 billion US$ in 2010, and if we look by prefecture, then Fukushima prefecture had the largest contribution at 23.2%.

Looking at **Figures 4.6** and **4.7**, then we can see that the affected prefectures in Tohoku region accounted about 62.7% and 62.6% of the agricultural production and the manufactured goods shipments, respectively.

4.3 Damage, restoration and reconstruction in the agriculture sector

4.3.1 Damage, restoration and reconstruction in the agriculture sector

On March 11, 2011, the 2011 GEJE and resultant tsunami hit East Japan, claiming the lives and property of many people. In particular, the agriculture and related industries were severely hit. Most of the agricultural land or farmlands were inundated with seawater, almost all the agricultural facilities in Miyagi, Fukushima, and Iwate Prefectures were badly damaged, and most agricultural crops were washed away as well. Damages related to the agricultural land and facilities and to the agricultural crops were reported to be over 8.8 billion US$ and 9.4 billion US$, respectively. Nevertheless, when losses associated with farmers' inability to work since being hit by the disaster, damage to processing facilities, and loss of processing capacities are combined, such damages are likely to be much larger than these amounts. **Table 4.1** describes the estimated area of farmland washed away, inundated, or damaged by the tsunami. In terms of the estimated area of farmlands damaged, Miyagi Prefecture suffered the most due to the disaster, in which 15,002 hectares – about 21.6% of the total planted area – were flooded by seawater. These farmland-damaged areas comprised some 12,685 Ha of paddy fields and 2,317 Ha of upland fields.

Table 4.1 **Estimated area of farmlands washed away, inundated, or damaged by the tsunami**

Prefecture	Planted Area (Ha)	Area of Damaged Farmland (Ha)		
		Total	Paddy fields area	Upland fields area
Aomori	46,900	79 (0.16)	76	3
Iwate	54,500	1,838 (1.33)	1,172	666
Miyagi	66,400	15,002 (21.60)	12,685	2,317
Fukushima	64,400	5,923 (8.48)	5,588	335
Ibaraki	77,100	531 (0.27)	525	6
Chiba	60,500	227 (1.10)	105	122
Total	**369,800**	**23,600 (5.81)**	**20,151**	**3,449**

Data source: Ministry of Agriculture, Forestry, and Fisheries
Note: Numbers in parentheses are estimated damaged areas shares of the planted areas

Furthermore, **Table 4.2** describes the damage to the agricultural sector in total and particularly in three of the prefectures in Tohoku. Damages related to agriculture were reported to be over 84.7 billion US$, of which about 91.3% were from three prefectures in Tohoku. Again, Miyagi Prefecture had severe losses due to the 2011 GEJE, namely about 55.7% of the total losses.

Table 4.2 **Damage to the agriculture in three affected prefectures in Tohoku region**

Major damage	**Total damage & number of places**	**Damage in Iwate**	**Damage in Miyagi**	**Damage in Fukushima**
Farmland (BUS$) (Places)	40.1 (18,186)	2.3 (13,321)	27.6 (1,495)	9.4 (1,799)
Agriculture purpose (BUS$) (Places)	27.5 (17,317)	0.6 (3,657)	12.1 (4,724)	9.3 (3,749)
Coastal conservation facilities(BUS$) (Places)	10.2 (139)	3.3 (15)	4.4 (103)	2.5 (20)
Rural community facilities (BUS$) (Places)	6.3 (450)	0.1 (41)	2.7 (107)	2.4 (141)
Crops such as damage costs (MUS$)	142	19	82	8
Agriculture, livestock related facility damage cost (MUS$)	492	28	351	13
Grand Total (BUS$)	**84.7**	**6.4**	**47.2**	**23.7**

BUS$:Billion US dollars, MUS$:Million US dollars

Data source: Ministry of Agriculture, Forestry, and Fisheries, as for July 5, 2012

Immediately after the disaster, the government implemented measures to procure and provide emergency food, beverages, charcoal, and briquette coal to temporarily restore agriculture and other facilities, to prevent secondary disasters, to supply feed, and to secure a stable rice supply in the Tokyo metropolitan area and other regions. The government also issued instructions on restrictions of the distribution of spinach, raw milk and other products in some regions in line with the fallout radionuclides due to the accident at TEPCO's Fukushima Daiichi Nuclear Power Station. In addition, on April 8, 2011, the government implemented a policy restricting rice planting in restricted areas, planned-evacuation areas, and areas prepared for evacuation in the case of emergency, as well as in areas where radioactive cesium was detected in paddy field soil.

Agriculture in Japan was an important component of the pre-war Japanese economy. Although Japan had only 16% of its land area under cultivation before the Asia-Pacific War in 1941, over 45% of households made a living from farming. Cultivated land was mostly dedicated to rice. Over the course of Japan's economic growth since the war, its agricultural, forestry, and fishing industries have come to employ fewer and fewer workers every year, and their respective shares of GDP shares have also dropped. The number of workers decreased from 14.39 million in 1960 (32.7% of the total workforce) to 2.38 million in 2010 (4.2% of the total workforce), and the GDP share of the industries fell from 12.8% in 1960 to 1.2% in 2010.

In 2012, the contribution of the agricultural sector to Japan's GDP is only about 1.2%, yet given that the agricultural sector is a very important sector in order to support the availability of food for Japanese people and to maintain Japan's food self-sufficiency ratio, the agricultural sector has become one of the top priorities for restoration and reconstruction. As most of the disaster-damaged areas are rural, it is important for Japan to restore and reconstruct the disaster-damaged areas, including the Tohoku region, as one of Japan's leading food supply bases, as soon as possible.

Significant progress has been accomplished towards rebuilding and revitalizing areas affected by the 2011 Great East Japan Earthquake disaster. Nevertheless, in the disaster-hit areas and elsewhere in the country, many people's lives are still greatly inconvenienced because of the damage. Those people include those who are still unable to return to their homes even now because of the nuclear accident. In the agricultural sector, the restoration plan for farming is on schedule, aiming to have approximately 90% of farmland back in operation in 2014, while the fisheries sector is also on its way to a full-scale recovery. There have also been numerous initiatives that support the revitalization of local economies through public-private partnerships, many of which are leveraging advanced technologies such as information and communication technology (ICT) and clean energy, as well as high-tech agricultural initiatives. The progress of agriculture performance, reflected in the GDP of agriculture and the production of rice, is presented in **Table 4.3**.

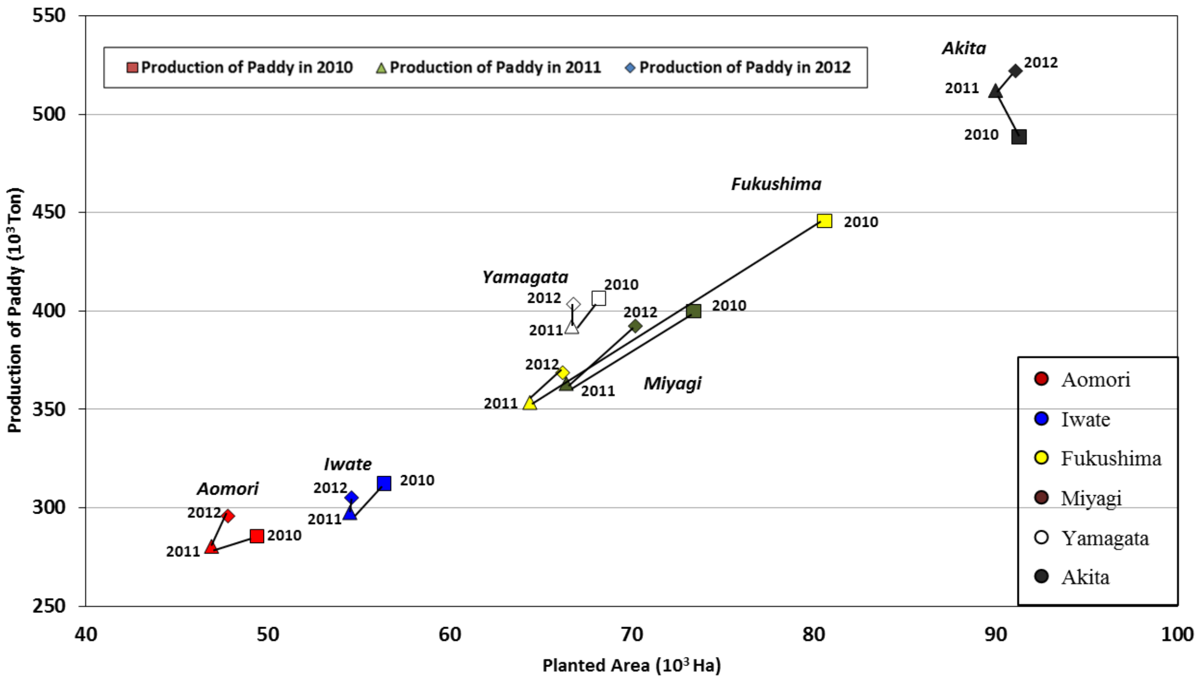
Table 4.3 **Gross agricultural products and rice production of major affected prefectures**

Prefectures	GDP of agriculture (Million US$)			Production of rice (1000 ton)		
	2010	2011	2012	2010	2011	2012
Total-Japan	82,549	79,545	83,290	8,487	8,405	8,522
Aomori Pref.	2,751	2,478	2,594	286	281	296
Iwate Pref.	2,287	2,330	2,440	313	298	305
Miyagi Pref.	1,679	1,776	1,859	400	363	392
Fukushima Pref.	2,330	2,304	2,412	446	354	369
Ibaraki Pref.	4,306	3,779	3,957	406	397	412
Tochigi Pref.	2,552	2,438	2,553	343	351	345
Chiba	4,048	3,815	3,995	333	322	334
Total of seven prefectures	19,953	18,920	19,810	2,527	2,366	2,453
Share of seven prefectures (%) in Total-Japan	24.17	23.79	23.78	29.77	28,15	28.88

Data source: Ministry of Agriculture, Fishery, and Forestry, 2010-2012

In the case of the restoration and reconstruction of the agricultural sector in Tohoku, **Figure 4.8**, which is a replication of **Figure 3.11**, shows the planted area and production by paddy by prefecture in Tohoku before, during, and after the 2011 GEJE. In 2011, the year when the disaster occurred, all prefectures except Akita experienced a decrease in production by paddy. Fukushima experienced the largest decrease in paddy production, followed by Miyagi, Iwate, Yamagata, and Aomori.

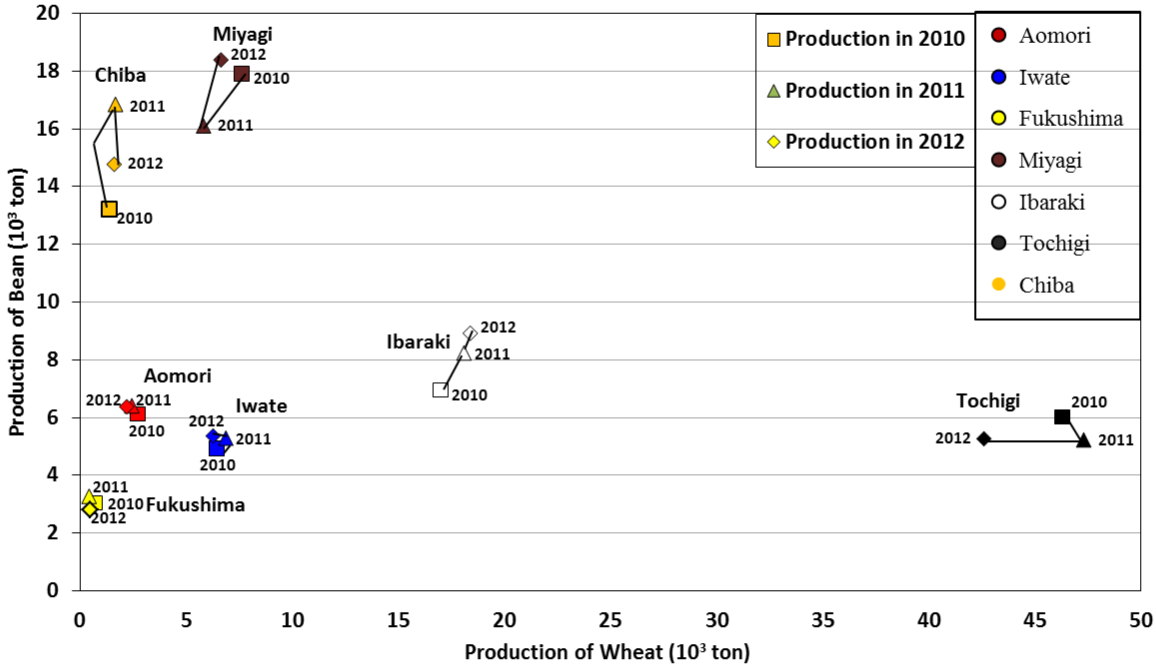
From **Figure 4.8**, among the prefectures that experienced a decline in paddy production, Aomori has had the fastest recovery in paddy production with the 2012 paddy production having surpassed the 2010 production; Fukushima, however, has had the slowest recovery in paddy production. One of the reasons is that, besides the earthquake and tsunami, Fukushima also suffered from the nuclear power plant accident, after which many people had to leave their hometown and, for health safety reasons, the production of paddy was deliberately reduced. In order to maintain the same level of rice production in Japan, the Japanese government redistributed the paddy production from Fukushima to other prefectures.



Data source: Ministry of Agriculture, Fishery, and Forestry, 2010-2012

Figure 4.8 **Planted area and production of paddy in Tohoku Region**

Figure 4.9 displays the production of wheat and beans in the affected prefectures, and apparently, some agricultural products such as wheat, beans, and buckwheat were not affected much by the disaster. This implies that the affected prefectures were not the major producer of these crops or the locations of the planting of these crops were far from the disaster area. The contribution of the affected prefectures to the whole country's production of wheat, beans, and buckwheat were 9.29%, 19.17%, and 22.72%, respectively. Also, we can see that Tochigi has the highest production of wheat inasmuch as its production was not affected much by the disaster. Miyagi and Chiba have the largest production of beans, and, clearly, as the prefecture that experienced the most severe impact of the disaster, the production of beans in Miyagi has significantly decreased. Interestingly, in spite of that severe impact on its agricultural sector, the production of beans in Miyagi in 2012 exceeded the production in 2010. This implies that the recovery performance in Miyagi, especially in the production of beans, has been conducted very well. Meanwhile, Fukushima has the lowest production of wheat and beans.



Data source: Ministry of Agriculture, Fishery and Forestry, 2010-2012

Figure 4.9 **Production of wheat and bean in affected prefectures**

4.3.2 Impact analysis on the agriculture sector

Our balanced panel data encompass 47 prefectures over the period 2000-2012. The data were obtained from various government institutions of Japan, including the Cabinet Office of Japan (CAO), the Ministry of Agriculture, Forestry and Fisheries (MAFF), the Ministry of Economy, Trade, and Industry (METI), the Ministry of Internal Affairs and Communications (MIAC), and from prefectural websites. To investigate the impact of the 2011 GEJE on the agricultural sector, we use the growth of gross agricultural product per farm household (GAP) as the dependent variable. Next, to examine the impact of the disaster on the affected and unaffected prefectures we run four regression models: one that includes all prefectures (N=47), a second with less-affected prefectures (i.e., prefectures in which the Disaster Relief Act was not applied; N=38), a third one using the affected prefectures (N=9), and finally one with the most affected prefectures (N=4).

Major natural disasters are likely to have a large negative impact on economic growth, whether in the short run or in the long run. Given that, the macroeconomic literature generally distinguishes short-run effects and long-run effects, the first recent attempt to empirically describe short-run macroeconomic dynamics of natural disasters was Albala-Bertrand (1993). By applying a simple macroeconomics model, he found that GDP increased after the disasters. We try to investigate the impact of uncertain and sudden shocks such as the 2011 GEJE on the output of the agriculture sector.

Following Levine et al. (2000), Bruno (2005), Noy and Vu (2010), Loayza and Olaberria (2012), Strobl (2012) and Bloom and Baker (2013), our model starts with an autoregressive model that includes various policy and institutional variables reflecting the prefecture heterogeneity in efficiency. Moreover, and of importance, it also includes a shock term (i.e., natural disasters):

$$y_{i,t} = \alpha y_{i,t-1} + \beta X_{i,t} + \gamma GEJE_{i,t} + \eta_i + \varepsilon_{i,t} \; ; \; i = 1, \ldots, N, \; t = 1, \ldots, T \qquad (4.1)$$

where the subscripts i and t represent prefecture and time period, respectively; α is the parameter for the lagged dependent variable, thus α captures the dynamic process; β represent the parameters for the explanatory variables; γ is the parameter for $GEJE_{i,t}$, the explanatory variables of interest, in which $GEJE_{i,t}$ is a binary variable that takes a value of 1 if the prefecture was affected by the 2011 GEJE, and 0 if otherwise; η is an unobserved prefecture-specific effect; and ε is an unobserved white-noise disturbance with constant variance σ_ϵ^2.

For explanatory control variables as proxy shocks other than the GEJE, we use the following five variables. Education is approximated by the ratio of junior high school graduates who continue to obtain further education. Infrastructure development is measured by the public work expenditure per capita. Preparedness and rehabilitation from disasters is proxied by the disaster relief expenditure per capita. It should be noted, however, that the spending of this fund is not only for earthquakes but also for all other natural disasters that might occur in Japan (i.e., storms, floods, and landslides) (Parwanto and Oyama, 2013). Welfare expenditure per capita is a measure of the responsibility of the government to improve the welfare of society. Inflation rate is a proxy for macroeconomic stabilization, with high inflation being associated with bad macroeconomics policies. Finally, one should also note that in this estimation, we implicitly assume that our GEJE variable as well as the other control variables are exogenous.

We further note that with the inclusion of the lagged dependent variable as one of the regressors, Eq. (4.1) is simply a dynamic panel model. Nevertheless, as pointed by Nickell (1981), this situation introduces a systematic bias in the estimator of the coefficient on the lagged dependent variable (Nickel, 1981), which could lead to biases in other coefficients in the model. In addition, according to Judson and Owen (1999), by using Monte Carlo simulations has shown that with balanced dynamic panels characterized by $T \leq 20$, and $N \leq 50$, the Kiviet bias-corrected least-squares dummy variable (LSDVC) estimator of α (the parameter on the lagged dependent variable) is better behaved than the Anderson-Hsiao and the Arellano-Bond estimators (Kiviet (1995), and Alberini and Filippini (2010)). Thus, based on this evidence and the fact that our dataset has N = 47 and T = 13 as well as addresses the bias problem, we estimate our dynamic models using the LSDVC estimators.

We use the Stata program *xtlsdvc* for estimating the parameters of the LSDVC models with bias correction as in Eq. (4.1) (Bruno, 2005). The regression result is presented in **Table 4.4** for the full sample, the less affected prefectures, the affected prefectures, and the most affected prefectures, respectively. From **Table 4.4**, all the estimated parameters of our variable of interest – the 2011 GEJE $(\hat{\gamma})$ – are statistically significant and have negative values. This implies that the disaster has had some negative impact on the growth of gross agricultural products. Furthermore, by looking at the magnitude of the impact of the 2011 GEJE on the agriculture sector by prefectures, then we can see that the magnitude for the less affected prefectures is the smallest and for the most affected prefectures is the strongest. This is understandable, for although the total contribution of GAP from the affected prefectures is about 30%, the effect of the disaster as a whole is offset by the less affected prefectures. Comparing the magnitudes in columns [2] and [4], the impact of the disaster on growth of GAP in the most affected prefectures is about three times greater compared to that in the less affected prefectures. This is because the agriculture sector is a leading sector in most prefectures in the Tohoku region.

Looking at the other control variables, the estimated parameter for lagged GAP $(\hat{\alpha})$ is both negative and significant. As pointed out by Pritchett (1997) and Baltagi (2000), initial output per capita not only captures the forces of diminishing returns and thus convergence, but also represents institutional and structural conditions that have a positive impact on economic growth, which supports the existence of a dynamic nature of the dependent variable. The estimated parameter for education $(\widehat{\beta_1})$ appears to have different signs, although none of them is statistically significant; the estimated parameter for public work expenditure $(\widehat{\beta_2})$ is also not significant. The estimated parameter for welfare expenditure $(\widehat{\beta_4})$ has positive coefficients, suggesting a beneficial impact on society. On the other hand, the estimated parameters for government expenditures on disaster relief $(\widehat{\beta_3})$ and for price inflation $(\widehat{\beta_5})$ carry negative coefficients, indicating the harmful nature of a large fiscal burden and macroeconomic instability. However, this fact should be interpreted cautiously as most of the major public infrastructure and safety buildings have been already built. Therefore, expenditures on these expenses have been decreasing in recent years, though the situation slightly changed after the disaster, especially in the affected prefectures.

Table 4.4 **Impact of the 2011 GEJE on growth of the gross agricultural products Estimation method: Bias-corrected least-squares dummy variable (LSDVC)**

Dependent variable: *Growth of gross agriculture products (GAP) per farm household*

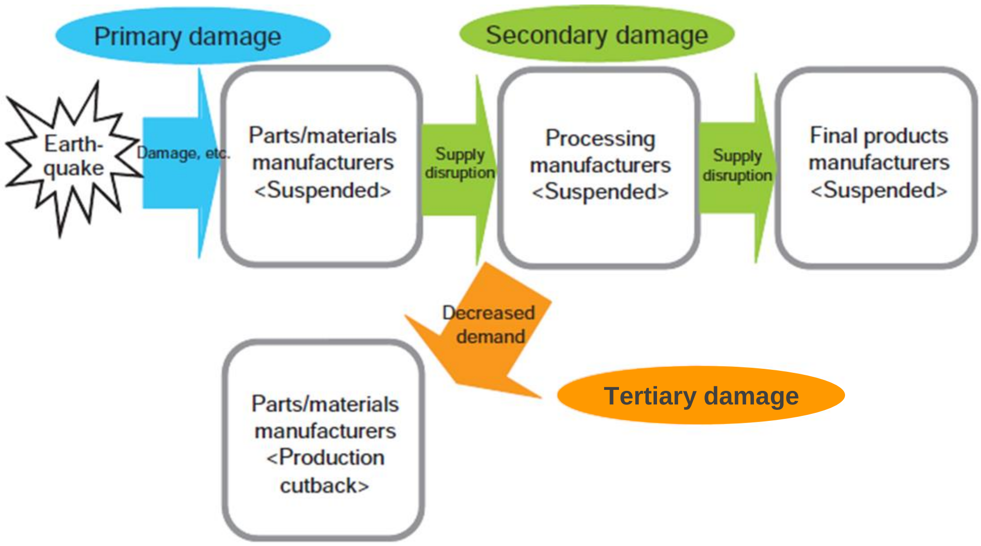
Variable	[1] All prefectures	[2] Less affected prefectures	[3] Affected prefectures	[4] Most affected prefectures
Natural disaster variable				
2011 Great East Japan Earthquake $(\hat{\gamma})$	-0.0866***	-0.0480***	-0.0882***	-0.1520***
	(0.0248)	(0.0165)	(0.0311)	(0.0504)
Control variables				
Initial growth of gross agriculture products per farm household $(\hat{\alpha})$	-0.2440***	-0.2670***	-0.2300**	-0.2930**
	(0.0481)	(0.0537)	(0.0929)	(0.1460)
Education (in logs) $(\widehat{\beta_1})$	-1.2600	-1.0590	0.9390	3.3350
	(1.0500)	(1.0550)	(3.1220)	(6.7330)
Public work expenditure per capita (in logs) $(\widehat{\beta_2})$	-0.0085	-0.0074	-0.0224	-0.0694
	(0.0241)	(0.0308)	(0.0505)	(0.0841)
Disaster relief expenditure per capita (in logs) $(\widehat{\beta_3})$	-0.0082*	-0.0069	-0.0140	-0.0045
	(0.0046)	(0.0048)	(0.0120)	(0.0277)
Welfare expenditure per capita (in logs) $(\widehat{\beta_4})$	0.0704**	0.1100***	0.0356	0.0520
	(0.0292)	(0.0348)	(0.0581)	(0.1030)
Inflation (log (100 + % Growth rate of CPI) $(\widehat{\beta_5})$	-3.9640***	-3.9820***	-4.2800***	-4.5680***
	(0.4980)	(0.6400)	(0.9970)	(1.5490)
Observations	505	406	99	44
Number of id	47	38	9	4

Notes: Numbers in parentheses are the standard errors.
Parameter estimates with ***, ** and * indicate significance at the 1, 5, and 10 percent levels, respectively.

4.4 Damage, restoration and reconstruction in the manufacturing sector

4.4.1 Damage, restoration and reconstruction in the manufacturing sector

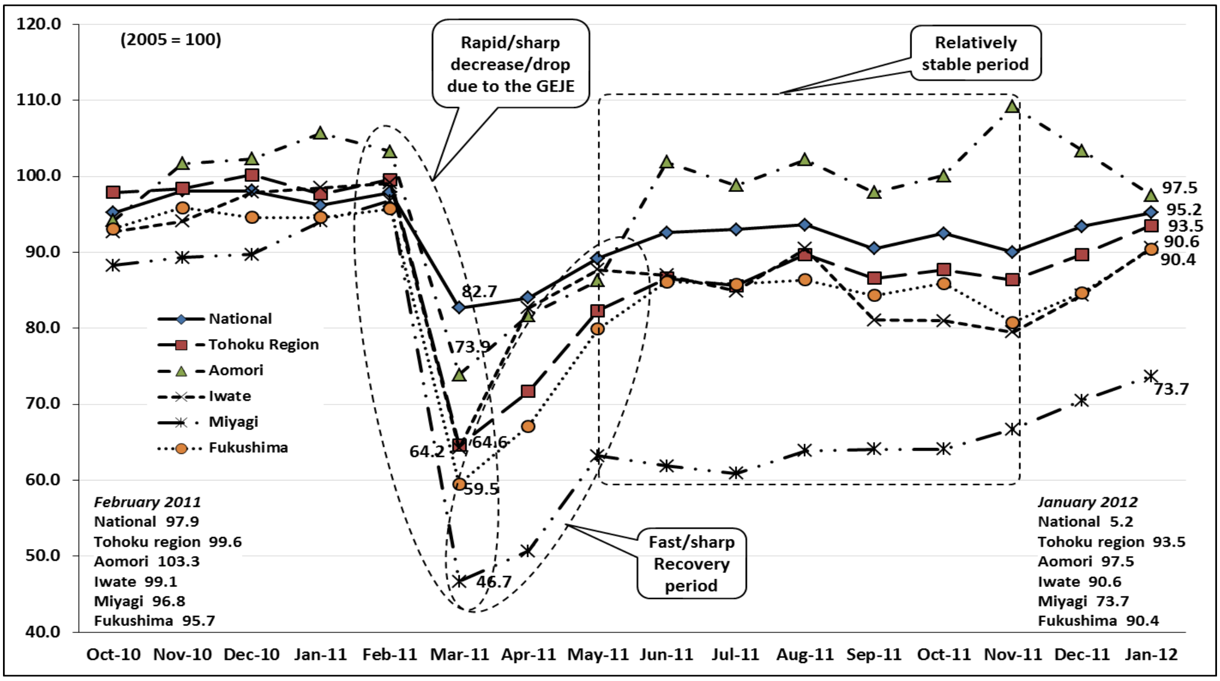
The 2011 GEJE caused about significant damage in the Tohoku and Kanto areas. Production disruption at affected firms has had extensive negative impacts on production activities in a wide variety of companies through supply chains surrounding the manufacturing industries. Since many firms do not fully understand the supply chains they belong to, negative impacts have spread out further. **Figure 4.10** depicts the impacts of earthquake damage on production activities.



Source: Ministry of Economy, Trade, and Industry

Figure 4.10 **Impacts of earthquake damage on production activities**

To identify the status of production activities of business establishments in the manufacturing industries, supply and demand trends of produced products, production plans of manufacturers for two months ahead, and production-related facilities and their operational statuses, the Index of Industrial Production (IIP) is often used. IIP is an abstract number, the magnitude of which represents the status of production in the industrial sector for a given period of time as compared to a reference period of time. **Figure 4.11** portrays the trend of IIP in Japan from October 2010 to January 2012.



Data source: Ministry of Economy, Trade, and Industry

Figure 4.11 **Trends of the Industrial Production Index (seasonally adjusted)**

In **Figure 4.11**, we can see that due to the natural disasters, the IIP for the first quarter of 2011 decreased compared to the previous period. Furthermore, the Tohoku region experienced a greater decrease than the entire country. Among the three worst affected prefectures, Miyagi had the highest decline in IIP, followed by Fukushima and Iwate. One of the possible reasons is because there is a greater amount of auto-related industry agglomeration in Miyagi compared to the other areas.

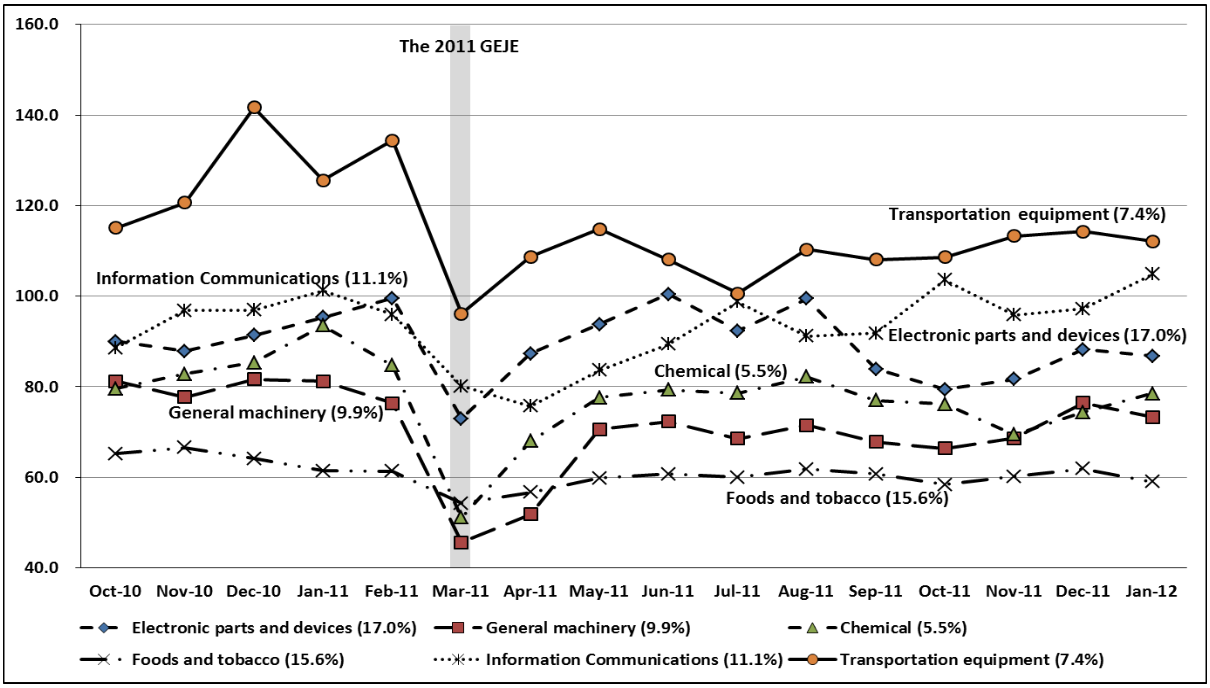
The Japanese government issued a primary supplementary budget in Fiscal Year (FY) 2011 of 5.94 billion US$ in total, of which some 5.1 billion US$ were used for financial support, leaving the remaining budget for restoration of factories and other facilities, energy supply facilities, and infrastructure. The main target of the financial support was small and medium enterprises (SMEs). Many SMEs were so badly damaged directly or indirectly by the 2011 GEJE that through METI the government through created a disaster response financial system known as the “Great East Japan Earthquake Recovery Emergency Guarantee”. The system offered drastically expanded credit lines and reduced interest rates applicable to credit guarantees and public loans to ensure that SMEs, including those indirectly damaged, would be able to cope with the disaster with minimal financial difficulty.

As depicted in **Figure 4.11**, the 2011 GEJE led to a decline in the value of the index of industrial production (IIP) in the first quarter of 2011. However, from the second quarter of 2011 the IIP started to increase. It was a remarkable that from September until November 2011, the IIP of Fukushima surpassed the IIP of Iwate. In January 2012, the IIP of Tohoku had approached the IIP of Japan, and the IIP of Iwate and Fukushima was almost the same, while the IIP of Miyagi remained far behind. Nevertheless, the values of IIP of neither Japan nor Tohoku have reached the levels seen before the 2011 natural disaster.

A breakdown by industry in the Tohoku region shows that the IIP decreased dramatically in the general machinery industry followed by the chemical and the transportation equipment industries. In the recovery period, the IIP increased dramatically in the general machinery and the chemical industries, followed by electronic parts and devices, though they still not yet reached its pre-disaster level. There is considerable variation by industry, with sluggish restoration being reported in the transport equipment industry, the foods and tobacco industry, and the information and communication industry (**Figure 4.12**).

Looking at **Figure 4.11** and **Figure 4.12** in more detail, we can distinguish three distinct IIP trends due to the 2011 GEJE, namely the sharp decrease of the IIP in February 2011-March 2011, the sharp recovery from March to May 2011, and the relatively stable period after May 2011. In the first period the sharpest decline was experienced by Miyagi from 96.8 to 46.7. This sharp decline was caused by a decrease in the IIP values of the pulp, paper and paper products industry, namely from 103.6 to

35, followed by decreases in the chemical, petroleum and coal product industry from 99.6 to 34.7 and the general machinery industry from 119.1 to 42.5. Fukushima also experienced a sharp decline in the first period (95.7 to 59.5). This decline was due to the decline of the IIP values of the non-ferrous metal industry from 98.0 to 44.9, the chemical industry from 115.9 to 55.1, and the foods and tobacco industry from 71.2 to 33.4. In Iwate the decline in the IIP value from 99.1 to 64.2 was due to the decline of the steel industry from 140.7 to 52.9, the general machine industry from 129.7 to 63.4, and the pulp, paper and paper products industry from 95.4 to 44.2. In addition, although it also declined, Aomori was the only one of the affected areas which had IIP values above those of the Tohoku region (103.3 to 73.9). The highest decline in Aomori was experienced by the pulp, paper and paper product industry and the steel industry, from 100 to 37.8 and from 78.2 to 31.7, respectively. Interestingly, while most industries in Aomori have undergone a decline in IIP value, the chemical industry had positive growth, from 24.4 to 59.4.



Data source: Tohoku Bureau of Economy, Trade and Industry Statistics

Figure 4.12 **Trends of the Industrial Production Index by industry in Tohoku**

In the two months after the disaster, namely in the second period, the manufacturing sector recovered quickly, which can be seen from IIP values. In spite of that recovery, their IIP values have not reached pre-disaster levels. Among the most affected prefectures in the Tohoku region, Iwate Prefecture experienced the fastest recovery, followed by Miyagi Prefecture, while Fukushima Prefecture had the slowest recovery in terms of its production activity status. In Iwate Prefecture, the index of industrial production was down by around 11.5% compared to pre-earthquake figures; against this background, the highest IIP growth occurred in the general machine industry (177%), followed by the pulp, paper, and paper products industry and the chemical industry at 155.9% and 72.2%, respectively. In the second period, Miyagi Prefecture still had the highest decline of IIP value compared to pre-disaster levels, which is 34.7%. In Miyagi Prefecture, the fastest recovery was experienced by the precision machinery industry at 78.8%, followed by the metal product industry (77.1%) and the general machinery industry (72.7%). In Fukushima Prefecture the IIP was down by around 16.5% compared to before the disaster. In the recovery period, the ceramic, stone and clay products industry had the highest recovery growth (80.7%), followed by the electronic parts and devices industry and the foods and tobacco industry at 74.2% and 71.6%, respectively. Figures for Fukushima Prefecture have remained at a lower level than those for Iwate and Miyagi Prefectures as the result of the effects of the nuclear accident. The third period shows that almost all manufacturing industries have recovered to about the same level as before the 2011 GEJE.

4.4.2 Analysis of impact on the manufacturing sector

To analyze the impact of the 2011 GEJE on the manufacturing sector we use the same method and the same explanatory or control variables were used to analyze the impact of the 2011 GEJE on the agricultural sector. The differences with the analysis in

Section 4.3 are the dependent variable, which is the growth of value added of manufacturing (VAM), and the first explanatory variable, which is the lagged VAM. The estimation results are shown in **Table 4.5**.

Table 4.5 **Impact of the 2011 GEJE on growth of the value added of manufacturing Estimation method: Bias-corrected least-squares dummy variable (LSDVC)**

Dependent variable: *Growth of value added of manufacturing per establishment*

Variable	[1] All prefectures	[2] Less affected prefectures	[3] Affected prefectures	[4] Most affected prefectures
Natural disaster variable				
2011 Great East Japan Earthquake ($\hat{\gamma}$)	-0.0624**	0.0280	-0.0432*	-0.1220*
	(0.0292)	(0.0192)	(0.0412)	(0.0653)
Control variables				
Initial growth of gross agriculture products per farm household ($\hat{\alpha}$)	-0.2740***	-0.2560***	-0.3850***	-0.2380
	(0.0461)	(0.0569)	(0.0994)	(0.1960)
Education (in logs) ($\widehat{\beta_1}$)	1.5410	1.0690	6.4090	8.2910
	(1.2390)	(1.2250)	(4.0880)	(8.7340)
Public work expenditure per capita (in logs) ($\widehat{\beta_2}$)	-0.0632**	-0.0699*	-0.0589	0.0110
	(0.0285)	(0.0362)	(0.0661)	(0.1180)
Disaster relief expenditure per capita (in logs) ($\widehat{\beta_3}$)	0.0147***	0.0129**	0.0358**	0.0262
	(0.0053)	(0.0057)	(0.0157)	(0.0363)
Welfare expenditure per capita (in logs) ($\widehat{\beta_4}$)	-0.0913***	-0.1250***	-0.0349	0.0287
	(0.0345)	(0.0400)	(0.0775)	(0.1350)
Inflation (log (100 + % Growth rate of CPI) ($\widehat{\beta_5}$)	1.7580***	1.6820**	1.6120	0.5980
	(0.5820)	(0.7370)	(1.2850)	(1.9250)
Observations	505	406	99	44
Number of id	47	38	9	4

Notes: Numbers in parentheses are the standard errors.
Parameter estimates with ***, ** and * indicate significance at the 1, 5, and 10 percent levels, respectively.

We can see that in **Table 4.5**, with the exception of Column 2 (less affected prefectures), the coefficients of our variable of interest, the 2011 GEJE ($\hat{\gamma}$) are also statistically significant, which implies that the disaster did not really impact the growth of the manufacturing sector in the less affected prefectures. In addition, the impact of the 2011 GEJE on the manufacturing sector in the most affected prefectures is the strongest. Compared to the coefficient values of the 2011 GEJE in **Table 4.4**, it appears that the estimated parameter values of *GEJE* $(\hat{\gamma})$ in **Table 4.4** are higher than those in **Table 4.5**. This fact implies that the disaster has had larger negative impacts on the agriculture sector than on the manufacturing sector. This also implies that, the total contribution from the affected prefectures in the agriculture sector (GAP) is larger than in the manufacturing sector (VAM) and that the process of recovery in the manufacturing sector was faster than in the agriculture sector (**Figure 4.11**).

Similar to the results in **Table 4.4**, the estimated parameter for lagged VAM $(\hat{\alpha})$ is also negative and significant across the different regressions presented in **Table 4.5**. Investment in education $(\widehat{\beta_1})$ exhibited positive signs, although, again, none of them is statistically significant. Government expenditure on disaster relief $(\widehat{\beta_3})$ was positive and significant, except in column (4), signifying that the manufacturing sector was benefitting from development of means of protection from disasters. On the other hand, government expenditures on public works $(\widehat{\beta_2})$ and welfare expenditure $(\widehat{\beta_4})$ returned negative values. These negative values justify that most of the prefectural government expenditures on public works and welfare have decreased in the period of observation. This is a logical result because most of the major public infrastructures in Japan have already been built, and there are only some minor infrastructure projects undertaken. Nevertheless, after the 2011 GEJE the government expenditure on public works and disaster relief were increased in some prefectures, particularly affected prefectures.

Different than reported in Section 4.3, the price inflation $(\widehat{\beta_5})$ turned out to have a positive and significant effect on VAM (except in columns 3 and 4). This signifies that the manufacturing sector has benefitted from an increased in price levels, although it is also possible that the rapid growth in the manufacturing sector has induced the rise in prices, which in turn has increased the value added in manufacturing. Of course, this hypothesis needs to be investigated further.

CHAPTER V

TRANSSHIPMENT NETWORK FLOW MODEL ANALYSIS FOR MEASURING THE ROBUSTNESS OF THE TRANSPORTATION SYSTEM

5.1 Logistics in Emergency and Past Research

Emergency is a serious, unexpected, and often dangerous situation requiring immediate action. While large-scale emergency is an emergency that may result in loss of life in large number and/or severe property damage. Large-scale emergencies are of high-consequence, low-probability (HCLP) events caused by substantial acts of nature, large human-caused accidents, and major terrorist attacks. According to the International Disaster Database (EM-DAT), the number of natural disasters has risen dramatically over the last four decades[17].

Natural disasters often cause huge fatalities and property damages, including infrastructures and transportation network (Parwanto and Oyama, 2013). Some large natural disasters caused many casualties and/or severe damage to infrastructure, which mainly caused by sudden natural disasters such as earthquake and its subsequent disasters, including Haiyuan Earthquake (1920), Tangshan Earthquake (1976), Hanshin-Awaji Great Earthquake (1995), Gujarat Earthquake (2001), Indian Ocean Earthquake and Tsunami (2004), Pakistan Earthquake (2005), Haiti Earthquake (2010), Tohoku Earthquake and Tsunami (2011), New Zealand Earthquake (2011), and also Bhola Cyclone (1970), Nevado del Ruiz Volcano Eruption (1985), Hurricane Andrew (1993), Hurricane Katrina (2005), and Cyclone Nargis (2008).

Shortly after a natural disaster occurred, many injury victims need to be immediately taken to the hospital or survivors need some vital needs for survival such as medicine, clean water or drinking water, and food, etc. Some residents may have

[17] Please see section 3.1 for figures and more detailed explanations.

reserve to the vital needs, although only in limited amount, while others may not. In most actual cases, some affected regions may have more supply than demand, and after satisfying their own demand, may still have excess supply, which we call Region with Excess Supply (RES). While, other affected regions might not be able to satisfy their own demand, which we call Region with Excess Demand (RED). Of course, that the affected region that experienced an excess demand (RED) is a region that should immediately get help in order to minimize the number of casualties as a result of the disaster. Necessary goods for survival must be immediately sent to this region. Thus, logistics in emergency can be defined as the distribution of relief/aid of vital need commodities under (large-scale) emergency, which are also known as *humanitarian logistics* or *relief operations*, carried out in the second phase of the disaster management as depicted in **Figure 1.3**.

Unfortunately, the situation sometimes becomes much worse when the disaster also causes severe damage to the existing infrastructure, such as roads, bridges, buildings, and other facilities. This uncertain condition related with each road segment's condition will certainly complicate the process of delivering relief to the victims. Making plans for the distribution of aid considering all possibilities that may occur is very important and necessary to be done. As pointed by Jiang (2011), specific characteristics of large-scale emergencies differ, depending on e.g. challenges for logistics in emergency in the aftermath of disasters.

This kind of situation makes the knowledge of aid logistics and supply chain management immensely important for humanitarian operations. One of the most recommended methods and often used for humanitarian operations is operation research (OR) technique, since it has been proven to be beneficial for different planning situation (Kovacs and Spens, 2007). Hence, given that the application of OR technique on emergent situation under uncertainty is scarce (Liu et al., 2007), this study will help us look into a rather "new" problem.

To obtain an optimal strategy for distributing necessary commodities to the damaged areas and transport them corresponding to their supply and demand situation as quickly as possible, we try to make necessary and desirable response strategies for managing emergent cases caused by various natural disasters. Our approach follows that by formulating multi-commodity transshipment network flow optimization models we try to find an optimal strategic solution under various types of uncertain situations. In addition, by assuming uncertainty related with each road segment's robustness, we apply Monte Carlo simulation technique in order to express supply-demand situations with respect to various commodities. This procedure would enable us measure the robustness and importance of the transportation network system quantitatively.

Wassenhove (2006) argued that disaster relief was about 80% logistics, therefore it would follow then that the only way to achieve this is through slick, efficient and effective logistics operations and more precisely, supply chain management. This condition makes the knowledge of aid logistics and supply chain management immensely important for humanitarian operations. And as mentioned previously, that one of the most recommended and often used for humanitarian operations is operations research (OR) technique. Altay and Green (2005) have summarized various applications of OR technique in disaster operations management as listed in **Table 1.2**.

Delivery planning in disaster relief operations has also been studied rather extensively. Ozdamar et al. (2004) proposed a logistics planning in emergency situations, which involves dispatching commodities to distribution centers in affected areas. Their model addresses the dynamic time-dependent transportation problem that needs to be solved repeatedly at given time intervals during the ongoing aid delivery period. Haghani and Oh (1996) developed a multi-commodity, multi-modal network flow model for disaster relief operations, in which they used penalty costs for unsatisfied demand.

On the other hand, Fiedrich et al. (2000) proposed a dynamic optimization model to find the best assignment of available resources to affected areas after an earthquake. In addition, Lin et al. (2009) developed a logistics model for disaster relief operations. They argued that geographic location for the depot is important, in which by increasing the number of vehicles they can improve the performance, and that reduction in the number of clusters does not guarantee an improvement in the logistics of humanitarian relief.

Meanwhile, Tzeng et al. (2007) proposed a multi-objective model for an optimal distribution of relief commodities, taking into account cost minimization, minimization of travel time, and maximization of satisfied demand. Vitoriano et al. (2010) also suggested a goal programming approach to support humanitarian organizations in aid distribution decisions. Yi and Ozdamar (2007) proposed different transportation and network flow models, in which they have also taken into account uncertainty, multiple aid items, and multiple time-periods.

In most of the above-mentioned studies, the preparation phase and the immediate response of disaster relief have been addressed, in which most of the problems fall into the transportation problem, namely they allow only shipments that go directly from a supply point to a demand point (Winston, 2003). Shipping scheduling problems more general characteristics are known as the transshipment problems. Nevertheless, fortunately, the optimal solution to a transshipment problem can be found by solving a linear programming transportation problem. Few studies have been conducted in this field. Herer et al. (2005) built up a transshipment model in a supply chain, which consist of one supplier and several retailers. Rootkemper et al. (2012) developed a mixed-integer programming model to minimize the unsatisfied demand and the operational costs by imposing penalty costs for unsatisfied uncertain demand.

We consider the situation such that large-scale emergent situation, caused by a serious natural disaster, has just emerged in a particular area. The area consists of several regions/cities, and has rendered significant damages on property and has inflicted human casualties, both death and injured. Some regions have experienced damages and losses severer than other regions. These regions should immediately get certain help in the form of consumable and durable commodities. Some emergency supplies must be transported from several supply centers/depots (airport/harbor or central inventory) to demand locations (e.g. affected regions). In addition, we assume that, in general, every region has a supply/stockpile of emergency vital needs, albeit for a relatively short time and in limited quantities. Thus, for a relatively short time (i.e. 1 or 2 days), the need of relief vital for survival, such as drinking water/clean water, food, and medicine/drugs can be supplied to the affected regions of natural disaster itself, in other words, the affected regions become both demand and supply regions.

Assuming that the main supply center (SC) may not be able to immediately operate, then the common practices follow that the available relief commodities to be sent immediately comes from the neighboring regions which are not affected at all or less affected with excess supply (RES) to the regions with excess demand (RED). However, the immediate relief consignments may not be able to satisfy all the demands too. Then, we need to transport the relief logistics from the supply center (SC) once they are become available. Hence, these problems will be solved by calculating the demand gap and transporting relief aid by using the shortest path technique.

In general, depending on the time when the SC can be established and operated, we may consider some stages to deliver relief aid to the affected regions. Firstly, we have the 1st stage where RES can deliver their surplus to RED. And if there is still remaining demand gap in RED, then we can have the 2nd stage where SC can deliver relief aid to satisfy all the remaining demand gap in RED.

We select the 2009 West Sumatra earthquake in Indonesia for our case study. Given that the Sumatra Island is an area included in the a zone of high seismic activity known as the "Pacific Ring of Fire", then earthquake is one of the natural hazard that can hit any time. Thus, a disaster management plan that includes emergency response preparations should be done as carefully and as quickly as possible, with the principle of "hope for the best but prepare for the worst".

Two earthquakes of 7.6 and 6.2-moment magnitude struck off the coast of West Sumatra, Indonesia on September 30, 2009, the first occurred at 17:16 and the second at 22 minutes later. The epicenter was 45 km west-northwest of the port city of Padang, the capital of West Sumatra and it had recorded depth of 71 km. A third earthquake of 6.8 magnitude struck an inland area 225 km southeast of Padang early the following morning (BNPB, 2009). The cumulative impact of these events left a broad swath of destruction. The earthquakes has caused serious damages to the housing and infrastructure of the communities in 13 regencies/cities[18], destroying livelihoods, and disrupting economic activity and social condition, causing extensive psychological trauma (BNPB, 2009 and Sugimin, 2011). Landslides in West Sumatra left scores of houses and several villages buried, i.e. three villages in the path of the disaster in Padang Pariaman regency appear to have been completely levelled and most of their

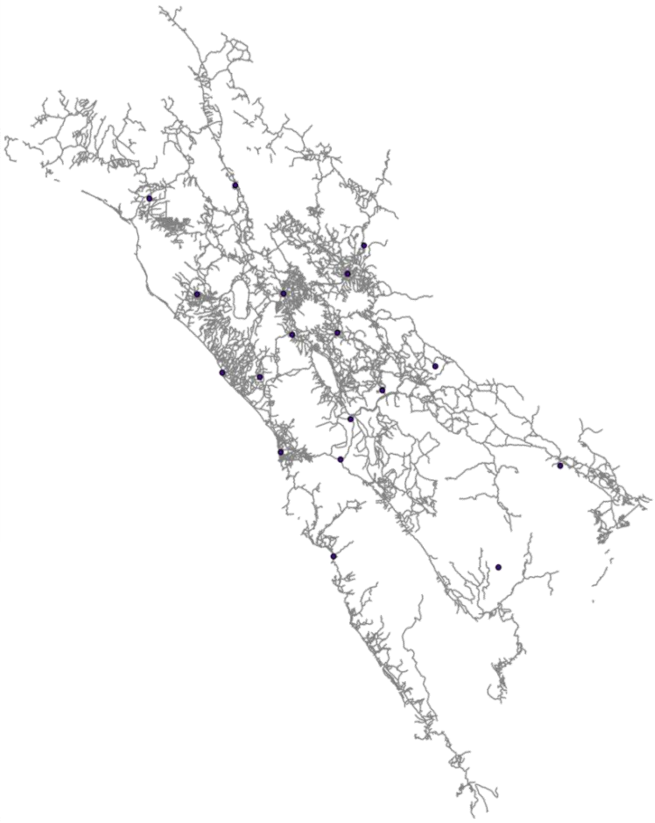
[18] Since our study will only consider transportation network using land vehicles, therefore we will exclude Mentawai Island regency from our analysis, because the available transportations from/to Mentawai Island are using the air and/or water transportation.

inhabitants may have been buried due to subsequent landslides. The number of casualties and property damages can be seen in **Figure 5.1**.

Source: National Disaster Management Board (BNPB) of Indonesia

Figure 5.1 **Number of casualties caused by the September 30, 2009 earthquake.**

Furthermore, to deliver some relief commodities to the affected regions, we need to know the road transportation network system of West Sumatra Province. However, it should be noted that the entire transportation road network system in West Sumatra province is large as it comprises of state roads, provincial roads, and district roads. And since we only deliver relief aid from SC, located in the provincial capital, namely Padang city, to the capital of the district/city or to the depot in each district/city. In other words, we assume that we only deliver the relief aid up to the SC of each affected region, mostly located in the capital of each regency/city rather than delivering the relief aid directly to the beneficiaries. Then we simplify the entire network system by simply taking the main roads linking the capital of the affected district/city, which consists of state roads and provincial roads. **Figure 5.2** shows the road transportation network system in West Sumatra province as a whole while **Figure 5.3** illustrates the simplified version of the road transportation network with 12 vertices and 22 edges.



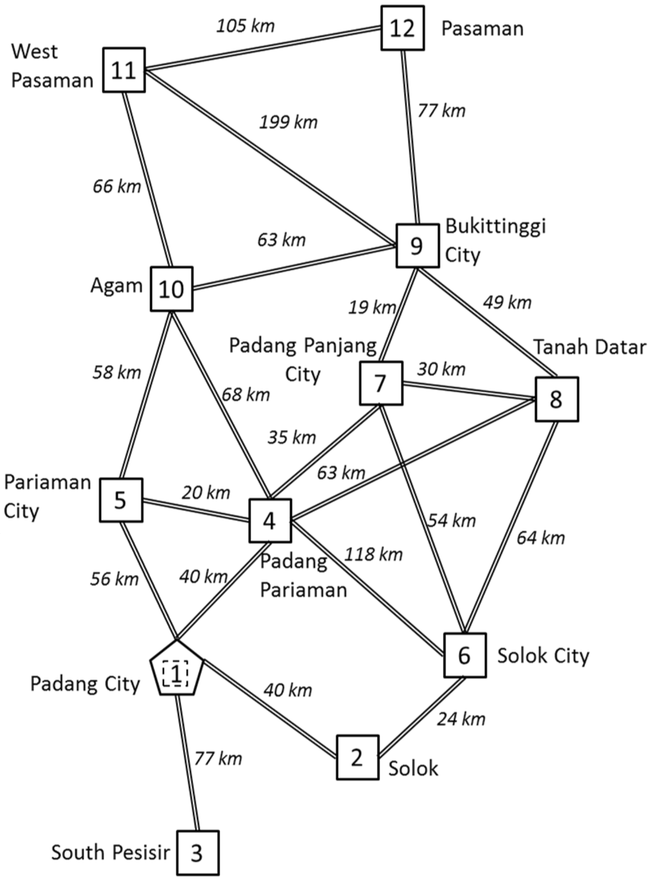


Figure 5.2 Figure 5.3

Figure 5.2 **Transportation road network system in West Sumatra**

Figure 5.3 **Simplified transportation road network system in West Sumatra**

5.2 Transshipment Network Flow Model for Humanitarian Operations

Our model considers two stages in delivering relief aid to affected regions, i.e. the Commodity Distribution stage as the 1st stage and the Shortage Clearance stage as the 2nd stage. In the 1st stage, at first we try to estimate the gap between supply and demand for each affected region, where some regions might have positive gap meaning that they have excess supply (RES), while others might have negative gap or excess demand (RED). Then we try to distribute supply from RES to RED with minimum cost. In the 2nd stage, given the solution that we obtain in the 1st stage, we try to satisfy all the remaining demand gap in RED.

5.2.1 The 1st Stage: The Commodity Distribution Stage

We define sets as follows: (a) N: the set of vertices, i.e. regions; (b) E: the set of edges (road segments) from region i to j $\{(i, j) \mid i \in N, j \in N\}$; and (c) K: the set of relief vital commodities, i.e. water, food, medicine, etc. We denote the following data input as: (a) $\{P_{ij} : (i, j) \in E\}$ for probability of the broken edge segment (road) between region i and j; (b) $\{S_{ik} : i \in N, k \in K\}$ and $\{D_{ik} : i \in N, k \in K\}$ for supply and demand for each region i and each commodity k, respectively; (c) $\{T_{ij} : (i, j) \in E\}$ for transportation cost (distance or travel time) for each road segment (i, j); (d) $\{V_k : k \in K\}$ for vehicle maximum load capacity for each commodity k; (e) $\{C_{ij} : (i, j) \in E\}$ for road capacity for each road segment (i, j); (f) $\{Q_k : k \in K\}$ for the amount of extra supplies in the supply center (SC) for commodity k. We define the decision variables of the model as follows: (a) $\{x_{ijk} : (i, j) \in E, k \in K\}$ is the amount of commodity k traversing road segment (i, j); (b) $\{v_{jk} : j \in N, k \in K\}$ is the demand gap at region j with respect to commodity k; (c) w_k is the maximum gap with respect to commodity k.

As the model is based on a network flow formulation, the constraints follow:

$$\sum_{i \in N, (i,j) \in E} x_{ijk} - \sum_{p \in N, (j,p) \in E} x_{jpk} + v_{jk} \geq D_{jk} \; ; \quad j \in N, k \in K \tag{5.1}$$

$$\sum_{k \in K} x_{ijk} \leq C_{ij} \; ; \qquad (i,j) \in E \tag{5.2}$$

$$\sum_{j \in N, (i,j) \in E} x_{ijk} \leq S_{ik} \; ; \qquad i \in N, k \in K \tag{5.3}$$

$$v_{jk} \leq w_k ; \qquad j \in N, k \in K \tag{5.4}$$

Constraint (5.1) expresses the demand constraint with more general conservation property, while constraint (5.2) reflects the road capacity constraint. Constraint (5.3) denotes the supply constraint, in which the amount of commodity k that transported from region i should not exceed the supply capacity of commodity k in region i. In addition, the amount of commodity k that transported to region j from all neighboring region i (in which region i is not the SC) may not satisfy the demand need in region j. In this case, we assume that the constraint (1) can be met by taking positive values for the variable v_{jk}. Moreover, the amount of commodity k transported to region j from the SC could meet the demand for commodity k in region j. Constraint (5.4) aims for calculating the maximum demand gap at region j with respect to commodity k.

Our linear programming model has two objectives, minimizing the transportation cost (i.e. distance or time travel) and minimizing the total demand gap. Combining the two objectives, we define the objective function of the model as follows:

$$minimize\ \boldsymbol{z_k} = K_1 \sum_{(i,j)\in E} T_{ij}\, x_{ijk} + K_2\, w_k \tag{5.5}$$

where $K_1 \geq 0$ and $K_2 \geq 0$

The value of K_1 represents the importance to minimize the transportation cost, while the value of K_2 reflects the importance to minimize the maximum demand gap. By assuming a fixed value of K_1 (e.g. $K_1 = 1$), if we emphasize more on the importance of minimizing the maximum demand gap, then we assign larger value of K_2. In the other hand, if we emphasize less on the importance of minimizing the maximum demand gap, then we assign smaller value of K_2.

To incorporate the uncertainty condition, we modify constraint (5.2) by adding the probability that the road segment $(i, j) \in E$ is not available (broken), that is:

$$\sum_{(i,j)\in E} x_{ijk} \leq \begin{cases} 0\ with\ probability\ P_{ij} \\ C_{ij}\ with\ probability\ (1 - P_{ij}) \end{cases} ; \qquad k \in K \tag{5.6}$$

Constraint (5.6) indicates that a road segment $(i, j) \in E$ is broken with the probability P_{ij}.

At first, we estimate the objective function (5.5) by assuming $P_{ij} = 0$, which implies that all road segments are available (survive). Then, for more general cases that the road segment may be broken with probability $0 \le P_{ij} \le 1$ will be estimating by using the computational procedure as described in **Table 5.1**, and as depicted in **Figure 5.4**:

Table 5.1 **Algorithm for the optimization model in the 1st stage**

Step 1:	Obtaining an optimal solution for the Reference case (K_1 = 1, K_2 = 0)	
Step 2:	Iterative computation (K_1 = 1, K_2 = 1,000,000)	
	Step 2-1:	Set t = 1
	Step 2-2:	Generate uniform random number $\{n_{ij}\}$ on [0, 1], $(i, j) \in E$
		Define edge capacity for each edge $(i, j) \in E$ as
		$C_{ij}^t = 0$ if $n_{ij} \le P_{ij}$ $= C_{ij}$ otherwise
	Step 2-3:	Solve the above optimization problem solution $\{z^t\}$, $\{x_{ijk}^t\}$, $\{v_{jk}^t\}$, $\{w_k^t\}$
	Step 2-4:	If $t > T$, then end; otherwise $t + 1 \to t$ Go to step 2-2
Step 3:	Find distribution for all solutions $\{z^t\}$, $\{x_{ijk}^t\}$, $\{v_{jk}^t\}$, $\{w_k^t\}$.	

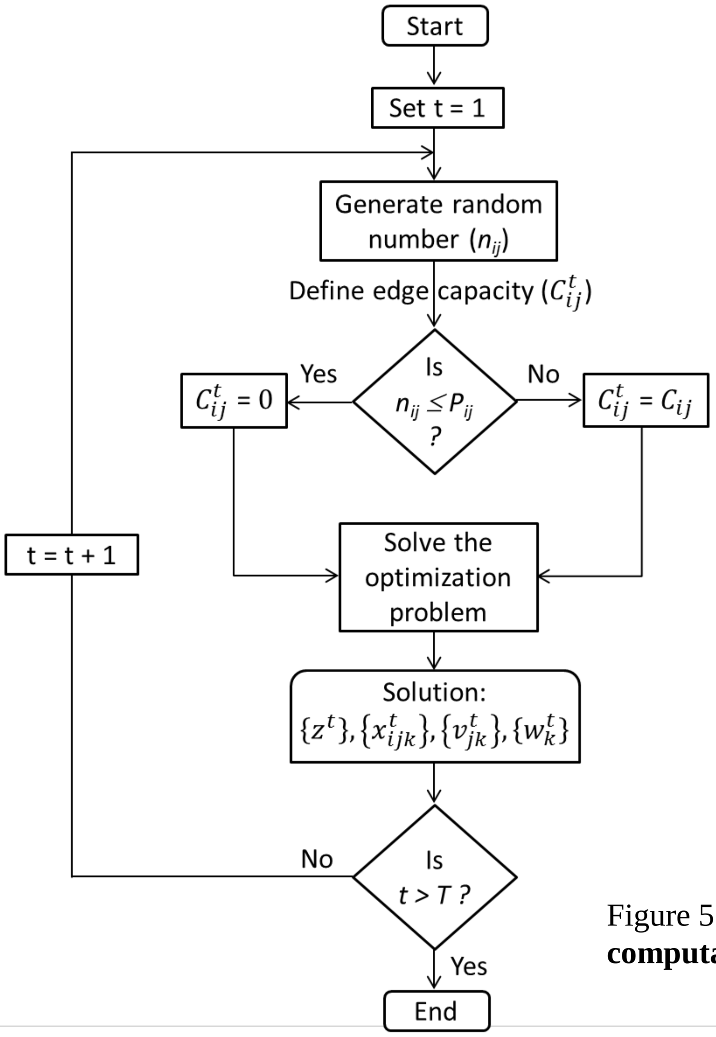


Figure 5.4 **Flow chart of the Iterative computation for the 1st stage**

5.2.2 Numerical Results for the 1st stage

As mentioned, we apply our linear programming model to our case study by assuming that all road segments $(i, j) \in E$ are available (survive), implies that $P_{ij} = 0$. Later, we will discuss more general cases where the road segment $(i, j) \in E$ might be broken with probability $0 \leq P_{ij} \leq 1$.

Table 5.2 describes the estimated demand and supply for each commodity, namely drinking water, food, and medicine/drugs which listed on a period basis, namely for 7 days (one week). The supply and demand columns describe the stockpile/reserve and the need for each commodity in each affected region, respectively.

Table 5.2 **Estimated demand and supply for drinking water, food, and medicine/drug to the need for one week by affected region**

No	Region	Drinking Water (M^3)			Food (Ton)			Medicine/Drugs (Ton)		
		Supply (S)	Demand (D)	Gap (S-D)	Supply (S)	Demand (D)	Gap (S-D)	Supply (S)	Demand (D)	Gap (S-D)
1	Padang city	843.37	984.02	-140.66	1,836.73	2,490.57	-653.84	25.48	81.74	-56.26
2	Solok regency	295.40	323.52	-28.12	32.94	14.99	17.95	10.47	0.25	10.22
3	South Pesisir regency	317.96	403.24	-85.28	940.84	186.30	754.54	13.05	1.70	11.35
4	Padang Pariaman reg	267.21	438.02	-170.81	817.59	2,744.30	-1,926.71	11.34	79.19	-67.85
5	Pariaman city	37.63	79.49	-41.86	148.37	368.32	-219.95	2.06	28.73	-26.67
6	Solok city	64.83	53.80	11.03	5.48	0.19	5.28	1.74	0.00	1.74
7	Padang Panjang city	66.52	50.79	15.73	2.49	9.20	-6.71	1.64	1.30	0.34
8	Tanah Datar regency	309.10	302.65	6.45	30.82	4.69	26.13	9.80	0.00	9.80
9	Bukittinggi city	134.87	96.93	37.94	4.75	0.65	4.10	3.14	0.00	3.14
10	Agam regency	318.73	387.66	-68.92	19.01	588.99	-569.98	12.55	11.36	1.18
11	West Pasaman reg.	21.92	304.41	-282.49	14.93	222.33	-207.40	9.85	1.75	8.10
12	Pasaman regency	230.21	235.19	-4.98	11.53	19.98	-8.45	7.61	0.00	7.61
	Total	**2,907.76**	**3,659.71**	**-751.95**	**3,865.49**	**6,650.52**	**-2,785.03**	**108.74**	**206.03**	**-97.30**
	Total Excess Demand			**823.12**			**3,593.04**			**150.78**
	Total Excess Supply			**71.15**			**808.01**			**53.49**

Note:
- A negative value of Gap indicates that the region is ***Region with Excess Demand (RED),*** while a positive value of GAP indicates that the region is ***Region with Excess Supply (RES)***;
- Total Excess Demand (TED) from RED is the summation of all negative value of Gap;
- Total Excess Supply (TES) from RES is the summation of all positive value of Gap.

Source: Author's calculations from various data sources, i.e. BNPB, PMI, BPK, PDAM, Police.

As mentioned in Section 5.1, the affected region should try to satisfy the demands using existing reserves in each region just after the natural disaster attacked. However, it can only last for a few days, not long after, then the increased demand and the diminishing supplies may lead to "gaps" between supply and demand in some affected regions, where relatively severe impacts of the natural disaster have been seen. Of course, this gap should be fulfilled as soon as possible by sending the commodity from the neighboring region that has excess supply (RES) and/or the supply center (*SC*).

Given the estimated data of demand and supply for some relief commodities as described in **Table 5.2**, **Figure 5.5** illustrates the condition of supply and demand of drinking water by region.

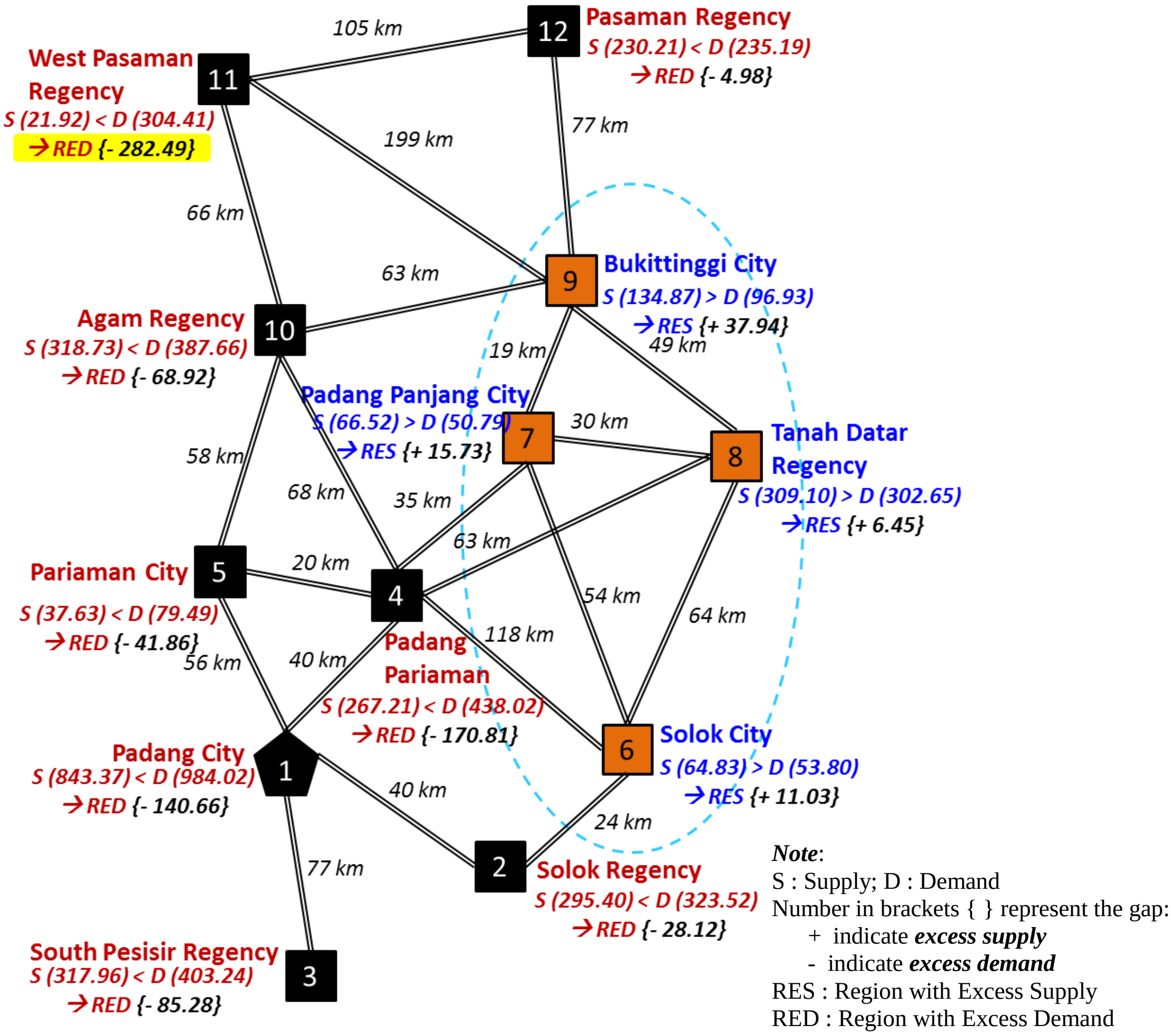


Figure 5.5 **Illustration of the supply and demand of drinking water (m^3) by region.**

From **Table 5.2**, we see that all commodities have larger total demand than total supply, which leads to "demand gap" for each commodity. Furthermore, we can also see that situation is different for each commodity in each region, for instance as depicted in **Figure 5.5**, regions 1, 2, 3, 4, 5, 10, 11, and 12 encountered excess demand for drinking water denoted by the RED where region 11 has the largest (maximum) demand gap; while regions 6, 7, 8, and 9 denoted by the RES experienced excess supply. Then, by assuming that the main SC takes some times to establish and/or operate, RES can deliver their excess supply to their neighboring RED.

As mentioned, in the 1st stage after estimating the gap, we try to deliver supply from RES to RED with minimum transportation cost by assigning small values for K_2. Then, we gradually increase the amount of supply to be delivered as we increase the value of coefficient K_2. **Table 5.3** shows the output of water delivery in the 1st stage, where we try to minimize two objectives, i.e. the transportation cost and the maximum demand gap, at the same time. For fixed value of K_1 (e.g. K_1 = 1), the gradual increase of supply delivery from RES to RED is seen by increasing the value of K_2 gradually.

Table 5.3 **Amount of drinking water delivered (m^3)**

K2	MaxGap (m^3)	TotalCost (km)	Total Excess Demand (m^3)		Total Excess Supply (m^3)		Routes	Amount of relief aid (Water) to be delivered (m^3)
			Original	Improved (Remaining)	Original	Improved (Remaining)		
100	282.49	0	823.12	823.12	71.15	71.15	-	0
110	282.49	0	823.12	823.12	71.15	71.15	-	0
120	282.49	0	823.12	823.12	71.15	71.15	-	0
130	244.55	4,894.26	823.12	785.18	71.15	33.21	9 → 10 → **11**	37.94 + 0 = **37.94**
140	244.55	4,894.26	823.12	785.18	71.15	33.21	9 → 10 → **11**	37.94 + 0 = **37.94**
150	228.82	7,222.30	823.12	769.45	71.15	17.48	7 → 9 → 10 → **11**	15.73 + 37.94 + 0 = **53.67**
160	228.82	7,222.30	823.12	769.45	71.15	17.48	7 → 9 → 10 → **11**	15.73 + 37.94 + 0 = **53.67**
170	228.82	7,222.30	823.12	769.45	71.15	17.48	7 → 9 → 10 → **11**	15.73 + 37.94 + 0 = **53.67**
180	222.37	8,370.40	823.12	763.00	71.15	11.03	7 ↘ 9 → 10 → **11** 8 ↗	15.73 + 37.94 + 0 = **60.12** 6.45 +
190	222.37	8,370.40	823.12	763.00	71.15	11.03	7 ↘ 9 → 10 → **11** 8 ↗	15.73 + 37.94 + 0 = **60.12** 6.45 +
200	222.37	8,370.40	823.12	763.00	71.15	11.03	7 ↘ 9 → 10 → **11** 8 ↗	15.73 + 37.94 + 0 = **60.12** 6.45 +
210 ~	**211.34**	**10,598.50**	**823.12**	**751.97**	**71.15**	**0.00**	6 → 7 ↘ 9 → 10 → **11** 8 ↗	11.03 + 15.73 + 37.94 + 0 = **71.15** 6.45 +

Source: Author's calculation.

In **Table 5.3** we can see that up until K_2 = 120 there is no supply delivery from RES to RED, implies that until K_2 = 120 we emphasize more on the importance of minimizing the transportation cost and less on the importance of minimizing the maximum demand gap. But, starting from K_2 = 130 some supply of drinking water have been delivered from RES to RED, that is from region 9 to region 11 (x_{ijk} = 37.94 m^3), making the maximum demand gap (w_k) and remaining gap (v_{jk}) at region 11 decrease to 244.55 m^3. We can also see that other RES (i.e. regions 6, 7, and 8) have not delivered their supply as we still emphasize more on minimizing the transportation cost. Nevertheless, we see no change for our optimal solution after we increase the value of K_2 over 210 as shown in **Table 5.3**. When K_2 = 210, we have the final optimal solution where all of the supplies from RES (x_{ijk} = 71.15 m^3) have been delivered to RED (i.e. region 11) and make w_k and v_{jk} at region 11 decrease to 211.34 m^3. **Figure 5.6** depicts the illustration of the routes to be travelled for delivering drinking water from RES to RED in the final optimal solution (i.e. K_2 = 210).

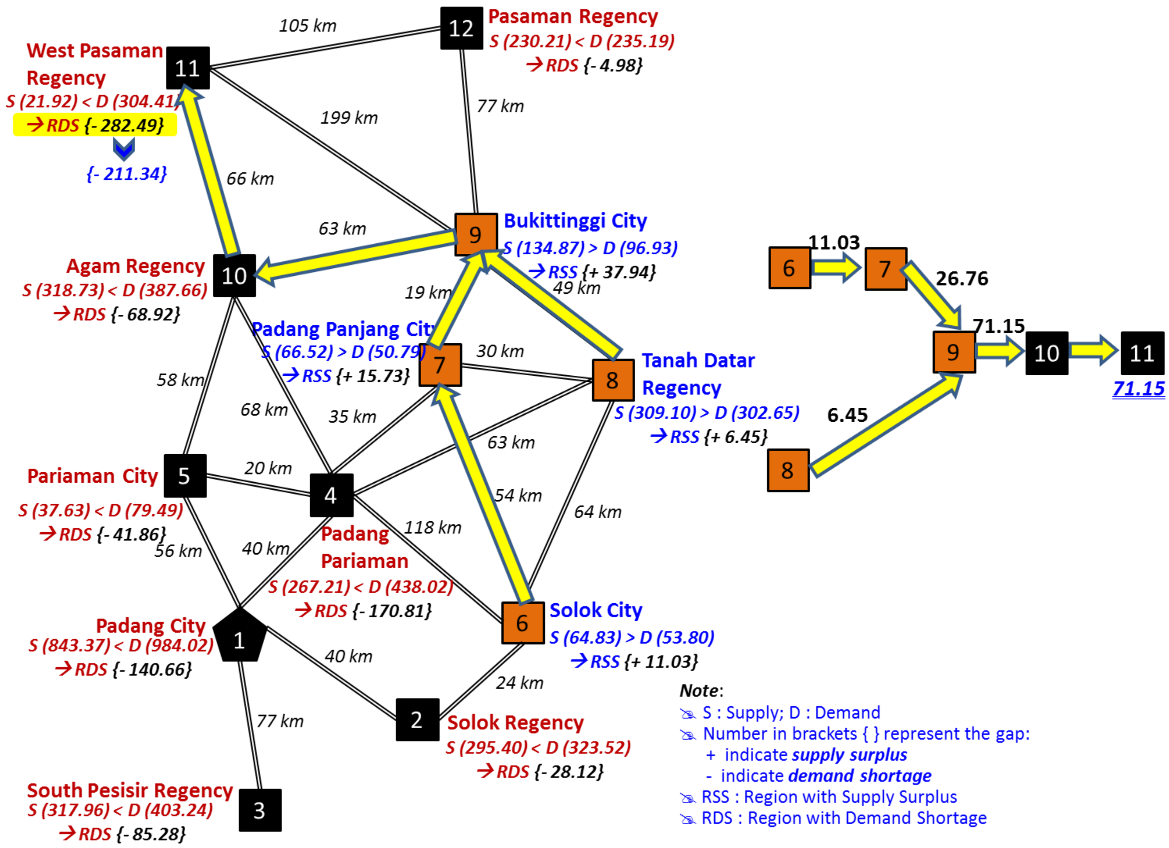


Figure 5.6 **Illustration for delivering drinking water from RES to RED (K_2 = 210)**

Hence, we can interpret K_2 as an average distance to fill the gap. For instance for K_2 = 130, the gap to be filled is 37.94 m^3, where K_2 = 130, the total distance to be travelled is 129 km (i.e. distance from regions 9 to 10 = 63 km plus distance from regions 10 to 11 = 66 km), so that in this case because 130 km > 129 km, then the drinking water can be transshipped to region 11 from region 9 through region 10. Thus, by increasing the value of K_2, we relax the condition for transshipment, implies that we allow for relief commodity delivery from RES to RED.

Furthermore, in **Table 5.3** we see that not all of the supplies from RES are delivered at once to RED, but gradually by increasing the value of K_2. However, we might have another possibility of delivering the supply from RES to RED, where we may want to deliver all the supply from RES to RED at once even for a small value of K_2. In this latter possibility we might have different solutions, for small K_2 that indicates we emphasize less on the importance of minimizing the maximum demand gap, the supply from RES will be delivered to the neighboring RED, regardless the amount of the gap in RED. While, for large K_2 that indicates we emphasize more on the importance of minimizing the maximum demand gap, the supply from RES will be prioritized to be delivered to RED with the largest demand gap. The solution of this possibility is presented in the **Appendix B** addition, by using the same fashion as to solve the delivery problem for the drinking water in the 1st stage, the solutions for the delivery problem for food and medicine in the 1st stage are given in **Appendix C**.

5.2.3 The 2nd Stage: The Shortage Clearance Stage

In the 2nd stage, the solution (output) of the 1st stage will be used as input, that is the remaining excess demand of relief aid in RED. Our assumption in the 2nd stage is that all the remaining demand of relief commodity in RED will be satisfied for each value of K_2. Denoting the set of destination I, define the data input as follows: (a) M: number of vehicles available simultaneously; (b) V: capacity of vehicle; (c) F: velocity of a vehicle; (d) T: maximum time horizon of delivery; (e) B: maximum number of batches; (f) D_i: demand at destination $\{i \in I\}$; (g) L_i: distance to destination $\{i \in I\}$; (h) N_i : number of vehicles needed for delivering to destination $i \in I$, i.e. $N_i = \lceil D_i / V \rceil$; (i) T_i

: time for delivering (two-way) to the destination $i \in I$, in which our model assumes it takes integer value for the sake of simplicity in formulation. Typically $T_i = \lceil 2 L_i / F + T_c \rceil$, where T_c is a transaction time, the decision variable of the 2nd model is a_{ij} : the number of vehicles for the delivery to destination *i* in *j*-th batch.

By applying the shortest path method, our objective function in the 2nd stage is to minimize the number of vehicles necessary for the delivery from the SC to destination in RED. This problem will be a transportation scheduling problem. The constraints are stated and explained as follows:

$$\sum_{j=1:B} a_{ij} \geq N_i, \quad \forall i \in I \tag{5.7}$$

$$\sum_{i \in I} a_{i,\, \lceil j/T_i \rceil} \leq M, \quad \forall j \in 1:T \tag{5.8}$$

$$a_{il} \leq C_{il}, \;\; \forall (i,\, l) \in E \tag{5.9}$$

The formulation of the objective function of our transportation scheduling problem:

$$minimize\ y = \sum_{i \in I} \sum_{j=1:B} a_{ij} 2^j \tag{5.10}$$

Constraint (5.7) is on the minimum number of vehicles necessary for the delivery to destination i. The summation is taken for all the batches to calculate the total number of vehicles necessary for destination i. Constraint (5.8) limits the total number of vehicles used at every hour. Constraint (5.9) is the road capacity constraint. In the objective function (5.10), the term 2^j is for weighting the late delivery more to avoid it.

5.2.4 Numerical Results for the 2nd stage

From the solutions obtained from the 1st stage, i.e. by comparing **Table 5.2** and **Table 5.3**, we can see that there are still remaining excess demands for each commodity in each region of RED. Assuming the main SC is now ready to operate then we can deliver relief commodities from SC to satisfy of all the remaining demand gap in RED. As explained, in the 2nd stage, the solution (output) of the 1st stage will be used as input with assumption that all the remaining demand of relief aid in RED will be satisfied for each value of K_2. As our objective is to deliver from the main SC, which is located at the provincial capital i.e. Padang city (Region 1), to the region that still have remaining excess demand (RED) as quick as possible, thus in solving this shortest path problem we exclude region 1.

Furthermore, in addition to the data given in **Table 5.2**, the estimated relief commodities available in the main SC are as follows: drinking water is 1,058.76 m^3, food is 3,837.63 tons, and medicine is 103.02 tons. The number of trucks for transporting food and medicine are estimated 56 and 13 vehicles, respectively, with maximum capacity per vehicle is 14 tons, while the number tanker truck for transporting drinking water is estimated 39 vehicles with maximum capacity per vehicle is 6 m^3. We also assign the following assumptions: vehicle velocity (F) is 30 km/hour, transaction time for loading (T_c) is 2 hours, maximum number of batches (B) is 10 batches, and maximum time horizon of delivery (T) is 48 hours.

In this numerical result for the 2nd stage, we will only present the solution for drinking water with K_2 = 210 as in **Table 5.4** and **Figure 5.7**, while the complete solution for drinking water can be seen in **Appendix D**. Furthermore, the complete solutions for delivering food and medicine from SC to RED are shown in **Appendix E**.

Looking at the results in **Appendix D** we can observe the changes in the number of vehicles necessary to deliver drinking water from the main SC to RED. In which, depending on the solution obtained in the 1st stage, we solve the 2nd stage that is to find the shortest path and minimize the number of vehicles necessary to deliver relief aid from SC to satisfy all the remaining demand gap in RED. As a logical consequence is, if we choose to minimize the maximum demand gap at the 1st stage, then at the 2nd stage, the number of vehicles necessary to deliver relief commodities to the region with the largest demand gaps can be reduced.

Table 5.4 **Scheduling and the number of vehicles necessary for delivering drinking water (units) (K_2 = 210)**

Region (One Batch Time, Cars)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2(5,5) :	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0
3(8,15) :	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
4(5,29) :	12	12	12	12	12	12	12	12	12	12	5	5	5	5	5	0	0	0	0	0	0	0	0	0
5(6,7) :	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	0	0	0	0	0	0
6(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10(10,12) :	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
11(14,36) :	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
12(14,1) :	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Total:	**39**	**39**	**39**	**39**	**39**	**39**	**39**	**39**	**39**	**39**	**31**	**31**	**29**	**29**	**28**	**22**	**22**	**22**	**21**	**21**	**21**	**21**	**21**	**21**

Region (One Batch Time, Cars)	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
2(5,5) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3(8,15) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4(5,29) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5(6,7) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10(10,12) :	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11(14,36) :	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	0	0	0	0	0	0
12(14,1) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total:	**16**	**16**	**16**	**16**	**16**	**16**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**0**	**0**	**0**	**0**	**0**	**0**

Source: Author's calculation.

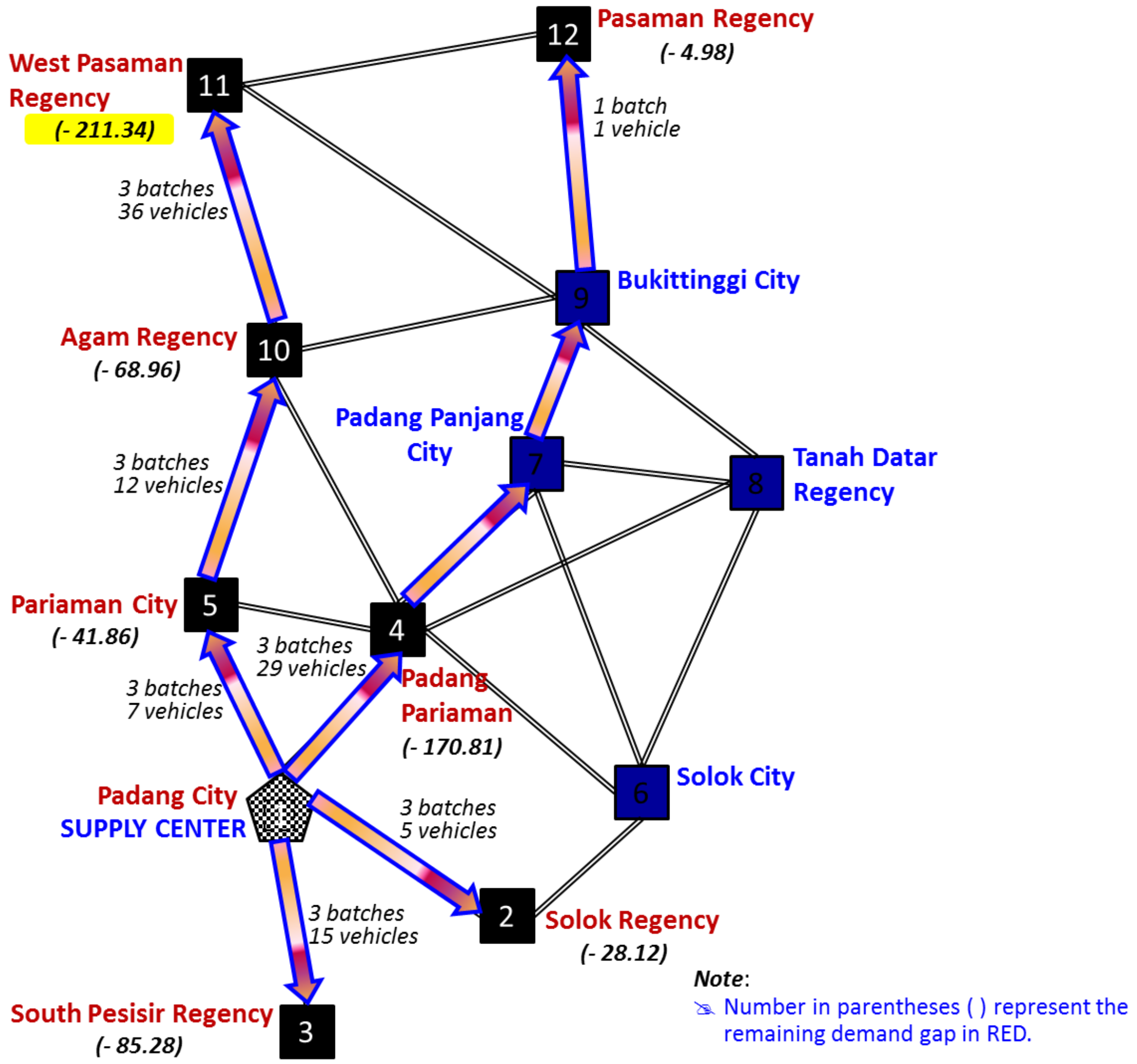


Figure 5.7 **Illustration for delivering drinking water from SC to RED (K_2 = 210)**

CHAPTER VI

SUMMARY AND POLICY IMPLICATIONS

6.1 Summary of the Model Results and Conclusions

This study aims to make the analysis and planning of disaster management in order to develop policies to mitigate the number of death and missing people (D&M) and/or property damages caused by natural disasters. Based on the time line of the disaster management, the analyses of the study are made in accordance with the actions taken in the three phases in disaster management, namely preparedness and mitigation, response, and recovery. In preparedness and mitigation stages, we investigate the past trend of natural disasters as well as investigate major factors to affect human casualties of natural disasters, focusing upon earthquakes and tsunamis that occurred in Japan and Indonesia. Then, we continue our investigation for measuring the damaging impacts of the 2011 Great East Japan Earthquake (GEJE) and also evaluating the recovery performance, especially on the agricultural and manufacturing sectors. Furthermore, as one of our contributions for the disaster response activities, we propose a multi commodity transshipment network flow optimization techniques under uncertainty in order to measure the robustness of the transportation network system for the emergent situation. As the case study, we apply the model to deliver relief commodities to the affected regions due to the 2009 West Sumatra earthquake.

Using about 100 years' data from 1900 to 2012, the study conducted in **Chapter II** aims to investigate the past trend of natural disasters, focusing upon earthquakes and tsunamis with respect to their occurrences and human casualties. We know that 100 years' data may not be enough to investigate the past trend of earthquakes and tsunamis. However, we believe these data measured under the almost same conditions would be sufficiently useful for our investigation. We apply mathematical policy analyses techniques in our natural disaster risk analysis and assessment in order to develop policies to mitigate the casualties caused by these natural disasters. Our study confirms that the exponential distribution fits the data of the inter-occurrence times between two consecutive occurrences of earthquakes and tsunamis, while the Poisson distribution fits the data of D&M.

For Japan and Indonesia, the average numbers of inter-occurrence times of earthquakes are 186.23 days and 167.77 days, respectively, whilst the inter-occurrence times of tsunamis are 273.31 days and 490.71 days, respectively. In addition, on average, the number of D&M per day caused by earthquakes in Japan and Indonesia are 0.578 and 0.395, respectively, whilst the numbers of D&M per day caused by tsunamis are 0.284 and 0.19, respectively. This finding implies that earthquakes are more frequent in Indonesia than in Japan, in the contrary, tsunamis are more frequent in Japan than in Indonesia. However, in terms of fatalities, earthquakes and tsunamis have caused more deaths in Japan than in Indonesia.

Regarding the relationship between D&M inflicted and some parameters of natural disasters, the study found that the magnitude of earthquake, focal depth of hypocenter, and location of epicenter has significant effect on the D&M inflicted in the case of earthquakes. In addition, parameter values of magnitude for Japan (178.78) is greater than Indonesia, this implies that in average the number of casualties caused by earthquakes in Japan is higher than in Indonesia (64.34). One possible cause is the population density in Japan is higher than in Indonesia.

While, in the case of tsunamis, factors that have significant effect on D&M is maximum water height and magnitude of earthquake. Where the parameter value of water height in Indonesia (56.55) is higher than Japan (27.11), imply that, although, tsunami is more frequent in Japan than Indonesia, however the D&M caused by tsunami in Indonesia tend to increase. This evidence could be a warning for those people who live near the shore or coastal areas, since they would be the first victims to be stricken if there is a tsunami. There should some rules related with the safe distance to build residences from the shoreline, or if there are some people who live in areas with a supposedly dangerous tsunami threat, the government should relocate them to some other safe places and/or build tsunami walls.

As has been elaborate in **Chapter III**, that in the last four decades, namely from 1970 to 2012, the number natural disaster events have been significantly increased over the globe; such increases are allegedly associated with the increasing population exposed to hazards. This increase is generally due to a significant increase of the small category of natural disasters, namely the natural disasters that resulted in the number of victims of less than 10,000 people. In addition, 40.8 percent of these natural disasters occurred in Asia.

In 2005 a turning point took place, in which most of the regions the frequencies of natural disasters started to decline. A fairly significant decline could be seen in Asia, namely, the average growth of natural disaster events (slope of the regression line) in Asia has decreased from 3.86 into -5.02. Only in Africa that the number of natural disaster during 1970-2012 shows consistent increase, whilst in Oceania the trend is rather flat. In terms of casualties, however, Asia was proportionally hit harder. Of all the number of D&M caused by natural disasters in the world from 1970 to 2012, as much as 57.45% is in Asia, followed by Africa (21.65%) and Americas (15.07%).

In Asia, the three most frequent natural disasters in Asia during 1970 to 2012 are flood, followed by storm and earthquake. However, in terms of D&M, earthquake claim the highest percentage of D&M (48.46%), followed by storm (38.96%) and flood

(10.06%). In addition, the cause of the declining trend of number of natural disasters in Asia was the declining trend of occurrences of flood and storm in Asia.

In **Chapter IV** we discuss about the recovery process of the 2011 GEJE that hit Japan on March 11, 2011. The earthquake then triggered a powerful tsunami and nuclear accident, making it the costliest compound natural disaster in the history of the world. Nine prefectures were declared as affected prefectures and thus received aid under the Disaster Relief Act; of those nine prefectures, four prefectures in Tohoku region that is Aomori, Iwate, Miyagi, and Fukushima suffered the greatest damage and loss, which made Tohoku as the most severely affected region in Japan due to the 2011 GEJE. Japan's economy, the world's third largest, slid back into recession due to the disasters. This natural disaster caused a 2.2% decrease in Japan's GDP By sector, the industrial sector including the manufacturing sector experienced the largest decrease, (-7.13%), followed by the agriculture sector (-3.64%) and the services sector (-0.85%).

In the agricultural sector, about 5.8% of the farmland was estimated to have been washed away, inundated, or otherwise damaged. The total number of damaged agricultural facilities and the total damage amount came to some 36,092 facilities and 84.7 billion US$, respectively, with Miyagi prefecture suffering the largest damage and losses, followed by Fukushima and Iwate. As the agricultural sector is a prominent sector for sustaining Japan's food self-sufficiency ratio, this sector became one of the top government priorities for restoration and reconstruction. Looking from the production of paddy as one of the substantial agriculture products, in Tohoku, Prefecture Aomori has the fastest recovery in paddy production as its production in 2012 has surpassed the production pre-disaster.

In the manufacturing sector, the 2011 GEJE brought about production disruption at affected firms, in which the disruption had extensive negative impacts on production activities in a wide variety of companies through the supply chains. The index of industrial production (IIP) for the second quarter of 2011 decreased compared to the previous period. At the national level, the IIP decreased by 3.97%, while in the Tohoku region it decreased by 8.13%. Nonetheless, in the 3rd quarter of 2011, the industrial production at the national level had recovered even though the value of IIP at the national level had not yet reached its pre-disaster level. This implies that the recovery process in the manufacturing sector in the affected areas, including the Tohoku region, in fact has not yet been optimally implemented. One of the possible reasons is because of the level of recovery of manufacturing is affected by the level of recovery of other sectors.

For a dynamic panel data model, several estimation techniques are possible. As a relatively small N and T characterize our dataset, we thus chose an econometric estimation technique judiciously. By using prefectural data from 2000 to 2012, we could use the bias-corrected least-squares dummy variable (LSDVC) to estimate the impact of the 2011 GEJE on the agricultural and manufacturing sectors, from which two major insights emerge. First, statistically, the 2011 GEJE had a significant negative impact on the agriculture and manufacturing sectors. On average, the impact on the agriculture sector was greater than on the manufacturing sector, namely, about two times higher. Second, in each sector, the impact of GEJE was perceived differently depending on the region. In both the agriculture and manufacturing sectors, the most affected prefectures experienced an impact about three times greater than the less affected prefectures.

Given the potential threats of disasters as earlier mentioned, which may hit at any time and any place, a humanitarian logistics or logistics in emergency should be well planned in advance. In such a situation, an optimal strategy on how to distribute necessary relief commodities to the damaged area and transport them corresponding to their supply and demand condition as quickly as possible is really needed. As part of the actions taken in the response phase, our transshipment network flow models as described in **Chapter V**, have tried to address this issue.

Depending on the time when the main supply center (SC) can be established and operated, we may consider some stages to deliver relief aid to the affected regions. If the SC cannot begin to operate immediately, then we can have 1st stage where regions that have excess supply (RES) can deliver their surplus to regions that have excess demand (RED). And if there is still remaining demand gap in RED, then we can have 2nd stage where SC can deliver relief aid in order to satisfy all the remaining demand gap in RED. Nevertheless, if the SC can begin operate immediately, then the 1st stage and the 2nd stage may run simultaneously. However, as the main supply center (SC) may have been destroyed/damaged by the disasters, the roads may survive, therefore, it is important to have several SC in different locations.

The optimal strategy in the 1st stage should take into account two objectives, namely minimize the transportation cost (i.e. distance or time travel) and the maximum demand gap. By assuming a fixed value of K_1, if we emphasize more on the importance of the total transportation cost then we assign lower value for K_2, otherwise, we assign higher value for K_2. Thus, the general strategy in the 1st stage to decrease (minimize) the largest excess demand is to find a set of regions with excess supply (positive value of Gap), and then try to connect those regions to the region with the largest (maximum) excess demand. And depending on the solution obtained in the 1st stage, we solve the 2nd stage that is to find the shortest path and minimize the number of vehicles necessary to deliver relief aid from SC to satisfy all the remaining demand gap in RED.

6.2 Concluding Remarks and Policy Implications

One of the findings of this study is that the occurrences of earthquakes and tsunamis tend to increase over time, both in Japan and Indonesia. This finding should be addressed judiciously and carefully, both by the government and by the people. To anticipate the impact of earthquakes, the government is expected to provide guidelines for earthquake-resistant house/building. Furthermore, the government should ensure its implementation, either through government regulation or careful supervision. In addition, the government is also expected to provide detailed information on areas prone to earthquakes, so that people do not build houses/buildings in such regions. In anticipation of the increasing tsunami threat, the government is expected to issue regulations on the construction of houses/buildings in coastal zones.

A reliable early warning system for earthquakes and tsunamis should also be provided by the government. We know that almost all tsunamis are caused by earthquakes, thus early tsunami warnings are indispensable to avoid large D&M so that residents including school children and senior people can evacuate safely to higher places. The system should be run reliably and be able to provide accurate information so that people can act properly and appropriately. Regarding the early warning system, since the 1995 Kobe earthquake, the Japanese government has invested about $1 billion in research and development of an Earthquake Early Warning (EEW) system. The Japan Meteorological Agency (JMA) implemented the system in December 2007. The flow of the EEW is as follows: when an earthquake strikes, seismographs near its source detect the first seismic waves (P-waves). P-waves are followed by more powerful secondary S-waves. JMA analyses the P-waves and estimates the intensity of the S-waves. If the S-waves are deemed to be sufficiently powerful to warrant alerting the public, the system automatically issues a warning. The warning is broadcast to the public through media, such as TV, radio, speaker, and mobile phones. Subsequently, after seeing or hearing an EEW, people have only a matter of seconds before strong tremors arrive, meaning that people need to act quickly to protect themselves. Furthermore, when an earthquake occurs, JMA also estimates the possibility of tsunami generation from the seismic observation data. If disastrous waves are expected in coastal regions, JMA issues a Tsunami Warning/Advisory for each region expected to be affected based on estimated tsunami heights. JMA also issues information on tsunami details such as estimated arrival times and heights.

Some disaster preparation activities should also be carried out on a regular basis, such as disaster drills, strengthening of buildings, and which also not less important is to convince and bring awareness to the community to be a safe community. In addition, the authorities should provide a reliable early warning system (EWS) containing accurate parameter information. EWS can become very useful means in risk mitigation, such as for earthquakes (Wenzel, 2011). Hence, when a disaster occurred, people instantly know what to do and what not to do. The cause of high number of D&M is unpreparedness when disaster strikes, resulting panic.

Furthermore, based on our study in **Chapter IV**, although it cannot be denied, that there are still many people's lives greatly inconvenienced because of the damage caused, mainly in the disaster-hit areas and elsewhere in the country, but there has been significant progress made towards restoration and reconstruction on the areas affected by the disaster in the two years since. One of the important lessons learned from the recovery process due to the 2011 GEJE is that nimble handling and comprehensiveness as well as good cooperation from all parties are the keys to success in restoration and reconstruction after any major disaster. According to MOFA, in the recovery process so far Japan has received assistance from 163 countries and 43 international organizations.

Every phase in the disaster management is very important and has its own difficulties and challenges. However, the phase, which consider has the highest critical level, is the response, the second phase. This is because at this stage the natural disaster has just occurred, so the amount of damage and casualties are not known with certainty and has the possibility to continue to grow. Therefore, to prevent this possibility to happen, then the handling at this stage is crucial since it is an emergency and thus must be done carefully and well planned.

In this regard, the government must have made a careful and good planning regarding the humanitarian logistics in advance. They should also make an inventory regarding the supply of relief commodities and always update the inventory, regarding the quantity and quality as well as the transportation modes, thus when they are needed then they can be delivered without delay.

Finally, we are aware that given the number of disasters seem to be prominent all corners of the globe, in which make no country nor community are fully protected from the risk of disasters. Therefore, in order to avoid a large amount of human losses and unnecessary demolition of infrastructure, disaster management strategies at each phase should be well planned and improved.

References

Albala-Bertrand J.M. 1993. Natural disaster situation and growth: A macroeconomic model for sudden disaster impacts. *World Development* 21 (9): 1417-1434.

Alberini A. and Filippini M. 2010. Response of residential electricity demand to price: The effect of measurement error. CEPE Working Paper No. 75 at http://www.cepe.ethz.ch/publications/workingPapers/CEPE_WP75.pdf (accessed 14 May 2014).

Altay N. and Walter G. Green. 2005. OR/MS research in disaster operations management. *European Journal of Operational Research* 175: 475-493.

Aragon G.O. and Philip E.S. 2012. Hedge funds as liquidity providers: Evidence from the Lehman bankruptcy: *Journal of Financial Economics* 103: 570-587.

Badan Nasional Penanggulangan Bencana (BPNB), Bappenas, and the Provincial and District/City Governments of West Sumatra and Jambi and International partners. West Sumatra and Jambi Natural Disasters: Damage, loss and preliminary needs assessment. 2009.

Baltagi B.H. *Econometric analysis of panel data*. 2000. England: John Wiley & Sons, Inc.

Bappenas-Indonesia (National Development Planning Board), Preliminary Damage and Loss Assessment: The December 26, 2004 Natural Disaster, Jakarta, 2005.

Barbarosoglu G. and Arda Y. 2004. A two-stage stochastic programming framework for transportation planning in disaster response. *J Operation Research Society* 55:43-53.

Bloom N. and Baker S.R.. 2013. Does uncertainty reduce growth? Using disaster as natural experiments. NBER Working Paper 19475.

BPS, Statistics of Banda Aceh, Indonesia, Aceh Province in Figures, various editions.

Bruno G.S.F. 2005. Approximating the bias of the LSDV estimator estimator for dynamic unbalanced panel data models. *Economics letters* 87: 361-366.

Bruno G.S.F. 2005. Estimation and inference in dynamic unbalanced panel-data models with a small number of individuals. *The Stata Journal* 5 (4): 473-500.

Cabinet Office of Japan. National Accounts of Japan (various editions: 2000-2012). http://www.esri.cao.go.jp/index-e.html.

Cameron A. Colin and Pravin K. Trivedi, Microeconomics Using Stata, Texas: Stata Press. 2009.

Dewey J. and Perry B. Earthquake Monitoring <http://earthquake.usgs.gov> [accessed 08.14.13].

Dore M and Etkin D. 2000. The importance of measuring the social costs of natural disasters at a time of climate change, *Australian Journal of Emergency Management* pp. 46-51.

Dore M. 03. Forecasting the Conditional Probabilities of Natural Disasters in Canada as a Guide for Disaster Preparedness. *Journal of Natural Hazards* 28: 249-269.

Dumontaux N. and Adrian P. 2013. Understanding the market reaction to shockwaves: Evidence from the failure of Lehman Brothers. *Journal of Financial Stability* 9: 269-286.

Dunbar P, McCullough H. 2012. Global tsunami deposits database. *Natural Hazards* 63: 267-278.

EM-DAT, The International Disaster Database by Centre for Research on the Epidemiology of Disaster (CRED), www.emdat.be.

FAO, 2005. Framework for Soil Reclamation and Restart of Cultivation, Aceh-Indonesia. Version 2: 1-16.

Fiedrich F., F. Gehbauer, and U. Rickers, 2000. Optimized resource allocation for emergency response after earthquake disasters. *Safety Science* 35: 41-57.

Gaustad G, Peterson R, and Kirchain R. 2008. Modeling Methods to Guide Recycling Friendly Alloy Design: The Impact of Compositional Data Structure. Proceedings of the Annual Meeting of TMS: 9th Global Innovations Symposium - Trends in Integrated Computational Materials Engineering for Materials Processing and Manufacturing, New Orleans, LA pp. 263-270.

Gusiakov VK. Tsunami History–Recorded, <http://www.tsun.sscc.ru/hiwg/PABL/Gusiakov_2008.pdf> [accessed 02.04.12].

Gusiakov V.K. 2005. Tsunami generation potential of different tsunamigenic regions in the Pacific. *Journal of Marine Geology* 215: 3-9.

Haghani A. and S.C. Oh. 1996. Formulation and solution of a multi-commodity multi-modal network flow for disaster relief operations. *Transportation Research Part A: Policy and Practice* 30: 231-250.

Hallegatte S, and Przyluski P. 2010. The Economics of Natural Disasters: Concepts and Methods, *World Bank Working Paper* <http://econ.worldbank. org> [accessed 01.14.12].

Herer Y.T., Tzur M., and Yuecesan E. 2006. The multilocation transshipment problem. *IIE Transactions* 38: 185-200.

Jiang Y, Yuan Y, Huang K, and Zhao L. Logistics for Large-Scale Disaster Response: Achievements and Challenges.

Judson R.A. and Owen A.L. 1999. Estimating dynamic panel data models: a guide for macroeconomists. *Economics letters* 65: 9-15.

Kiviet J.F. 1995. On bias, inconsistency, and efficiency of various estimators in dynamic panel data models. 68: 53-78.

Kossobokov V.G. 2012. Earthquake prediction: 20 years of global experiment. *Natural Hazards*: 1-23, <www.scopus.com> [accessed 08.12.12].

Kovacs G. and Spens K.M. 2007. Humanitarian logistics in disaster relief operations. *Int J Phys Distrib Logist Manage* 37(2):99-114.

Levine R., Loayza N., & Beck, T. 2000. Financial intermediation and growth: Causality and causes. *Journal of Monetary Economics* 46 (1): 31–77.

Lewis-Beck, Alan B, and Tim FL., *Social Science Research Methods*, Vol. 1, California: Sage Publications, Inc., 2004.

Lin Y.H., Rajan B., Peter A.R., Alan B., and Marie F. 2009. Application of a Humanitarian Relief Logistics Model to an Earthquake Disaster. (http://www.acsu.buffalo.edu/~batta/TRB_Updated.pdf) [accessed 01.04.14].

Liu D, Jiye Han, and Jianming Zhu. Vehicle Routing for Medical Supplies in Large-Scale Emergencies.

Loayza N.V. and Olaberria E. 2012. Natural disasters and growth: going beyond the averages. *World Development* 40 (7): 1317-1336.

Lyons M. 2009. Building back better: The large-scale impact of small-scale approaches to reconstruction. *World Development* 37 (2): 385-398.

MathWave Technologies, data analysis and simulation, < http://www.mathwave.com/>.

Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF), Statistical Yearbook of Ministry of Agriculture, Forestry and Fisheries, various editions.

Ministry of Agriculture, Forestry and Fisheries of Japan. 2013. The Damages caused by the Great East Japan Earthquake and actions taken by MAFF (last updated on March 12, 2013). http://www.maff.go.jp/j/kanbo/joho/saigai/higai_taiou/index.html.

Ministry of Economy, Trade and Industry. Census of Manufactures (various years). http://www.meti.go.jp/english/statistics/tyo/kougyo/index.html.

Nanto D.K, Cooper W.H, and Donnelly J.M. 2011. Japan's 2011 Earthquake and Tsunami: Economic Effects and Implications for the United States. *Congressional Research Service*, <www.fas. org/sgp/crs/row/R41702.pdf> [accessed 02.06.12].

National Geophysical Data Center/World Data Center (NGDC/WDC) Global Historical Tsunami Database, Boulder, CO, USA. (Available at http://www.ngdc.noaa.gov/ hazard/tsu_db.shtml)

National Geophysical Data Center/World Data Center (NGDC/WDC) Significant Earthquake Database, Boulder, CO, USA. (Available at http://www.ngdc.noaa. gov/hazard/earthqk.shtml)

Nickell S. 1981. Biases in dynamic models with fixed effects. *Econometrica* 49(6): 1417-1426.

Noy I and Vu T.B. 2010. The economics of natural disasters in a developing country: The case of Vietnam. *Journal of Asian Economics* 21: 345-354.

Noy I. 2009. The macroeconomic consequences of disasters. *Journal of Development Economics* 88: 221-231.

Oki S, and Nakayachi K. 2012. Paradoxical effects of the record-high tsunamis caused by the 2011 Tohoku earthquake on public judgments of danger. *International Journal of Disaster Risk Reduction*, <http://dx.doi.org/10.1016/j.ijdrr.2012.07 .002> [accessed 08.17.12].

Oyama T. and T. Uriu, 2011. Quantitative Data Analysis for Natural Disasters Mitigation, Paper presented at the Japan-China Joint Workshop on Accident Prevention and Disaster Mitigation Policy in Tokyo, Japan. <http://www.grips. ac.jp/docs/2011_News/110729-546.html> [accessed 01.04.12].

Ozdamar, L, Ediz E, and Beste K. 2004. Emergency Logistics Planning in Natural Disasters. *Annals of Operations Research* 129: 217-245.

Parlak A.I., Lambert J.H., Guterberk T.M., Clements J.I. 2012 Population behavioral scenarios influencing radiological disaster preparedness and planning. *Journal of Accident Analysis and Prevention* 48: 353-362.

Parwanto N.B. and Oyama T. 2013. A statistical analysis and comparison of historical earthquake and tsunami disasters in Japan and Indonesia. International Journal of Disaster Risk Reduction. http://dx.doi.org/10.1016/j.ijdrr.2013.10.003.

Porfiriev B. 2012. Economic issues of disaster and disaster risk reduction policies: International vs. Russian perspectives. *International Journal of Disaster Risk Reduction* 1: 55-61.

Pritchett L. 1997. Divergence, big time. Journal of Economic Perspectives 11 (3): 3-7.

Reconstruction Agency. Progress to date. <http://www.reconstruction.go.jp/english/topics/2013/03/industry-and-economy.html> [accessed 05.29.13]

Reconstruction Design Council. Towards Reconstruction "Hope beyond the Disaster", Report to the Prime Minister of the Reconstruction Design Council in response to the Great East Japan Earthquake. Tokyo, Japan, 2011. <www.cas.go.jp/jp/fukkou/english/pdf/report20110625.pdf> [accessed 27.05.13].

Rehabilitation and Reconstruction for Aceh and Nias (BRR), Tsunami Recovery Indicators Package, various editions, Banda Aceh.

Rottkemper B., Kathrin F., and Alexander B. 2012. A transshipment model for distribution and inventory relocation under uncertainty in humanitarian operations. *Socio-Economic Planning Sciences* 46: 98-109.

StataCorp. Data analysis and statistical software <http://www.stata.com>.

Statistics Bureau of Ministry of Internal Affairs and Communications. Japan Statistical Yearbook (various editions). http://www.stat.go.jp/english/data/nenkan/.

Strobl E. 2012. The economic growth impact of natural disasters in developing countries: Evidence from hurricane strikes in the Central American and Caribbean regions. *Journal of Development Economics* 97: 130-141.

Sugimin P. 2011. Lesson Learned: Rehabilitation and Reconstruction West Sumatra September 30th, 2009 Earthquake.

Suppasri A, et al. 2012. Damage and reconstruction after the 2004 Indian Ocean tsunami and the 2011 Great East Japan tsunami. *Journal of Natural Disaster Science* 34(1): 19-39.

Suppasri A, et al. 2012. Lessons Learned from the 2011 Great East Japan Tsunami: Performance of Tsunami Countermeasures, Coastal Buildings, and Tsunami Evacuation in Japan, *Journal of Pure and Applied Geophysics* pp. 1-26, <www.Springerlink. com> [accessed 08.12.12].

Suppasri A, et al. 2012. Mapping of historical tsunamis in the Indian and Southwest Pacific Oceans. *International Journal of Disaster Risk Reduction* <http://dx.doi.org/10.1016/j.ijdrr.2012.05. 003> [accessed 08.17.12].

Suppasri A, et.al. 2012. Tsunamigenic Ratio of the Pacific Ocean earthquakes and a proposal for a Tsunami Index. *Natural Hazards and Earth System Sciences* 12: 175-185.

T. Oyama, Y. Ohki, K. Ozaki, M. Honda, K. Kusumoto, and H. Muraki. 2011. Survey Data Analyses for Investigating Great East Japan Earthquake Damages. Paper presented at the Japan-China Joint Workshop on Accident Prevention and Disaster Mitigation Policy in Tokyo, Japan. <http://www.grips.ac.jp/docs/ 2011_News/110729-546.html> [accessed 01.04.12].

The National Police Agency of Japan. 2014. Damage Situation and Police Counter-measures associated with 2011 Tohoku district – off the Pacific Ocean Earthquake [as May 9, 2014]. http://www.npa.go.jp/archive/keibi/biki/ higaijokyo_e.pdf.

The World Bank. The recent earthquake and tsunami in Japan: Implications for East Asia. East Asia and Pacific Economic Update, 1 (2011). http://siteresources. worldbank.org/INTEAPHALFYEARLYUPDATE/Resources/550192-1300567391916/EAP_Update_March2011_japan.pdf <Accessed August 2013>.

Tohoku Bureau of Economy, Trade and Industry. 2012. The reconstruction of the Tohoku region. September 2012. http://www.tohoku.meti.go.jp.

Tzeng G.H., Cheng H.J., and Huang T.D. 2007. Multi-objective optimal planning for designing relief delivery systems. *Transportation Research E* 43: 673-686.

UNESCO. Learning from the Great East Japan Earthquake and Tsunami 2012, <http://www.unesco.org/new/en/natural-sciences/ioc-oceans/single-view-oceans/news/learning_from_the_great _east_japan_earthquake_and_tsunami/> [accessed 05.05.12].

United Nations – Economic and Social Commission for Asia and Pacific (UN-ESCAP), The Asia Pacific Disaster Report: Protecting Development Gains, 2010.

United Nations. West Sumatra Earthquake: Humanitarian response plan in coordination with the Government of Indonesia. 2009.

USGS. Today in Earthquake History: June 15th and March 2nd [accessed 08.13.13].

Van Wassenhove LN. 2006. Humanitarian aid logistics: supply chain management in high gear. *J Operational Research Society* 57: 475-489.

Vitoriano B., Ortuno M.T., Tirado G., and Montero J. 2010. A multi-criteria optimization model for humanitarian aid distribution. *J Global Optimization* http://doi:10.1007/ s10898-010-9603-z.

Vose D. Fitting distributions to data, 2010, <http:// www.vosesoftware.com> [accessed 03.11.12].

Wenzel F, et al. 2001. Potential of Earthquake Early Warning System. *Journal of Natural Hazards* 23: 407-416.

Wildt, Albert R. and Olli T. Ahlota, Analysis of Covariance. Sage University Paper on *Quantitative Applications in the Social Sciences*, 07-012. Newbury Park, CA: Sage. 1978.

Winston WL., *Operations Research Applications and Algorithms*, 4th ed., California: Duxbury Press, 2003.

Y. Sakamoto, M. Ishiguro and G. Kitagawa. 1986. Akaike Information Criterion Statistics. *Mathematics and Its Applications* (Japanese Series). Holland: KTK Scientific Publishers.

Yegulalp. 2010. A Brief study of largest earthquake magnitudes in the Northwest Pacific Region.

Yi W. and Ozdamar L. 2007. A dynamic logistics coordination model for evacuation and support in disaster response activities. *European Journal of Operation Research* 179: 1177-1193.

Offer of Assistance from Foreign Countries, Regions and International Organizations (as of September 15)

Japan has received, so far, offers of assistance from the following 163 countries and regions, and 43 international organizations (in alphabetical order).

(Asia)

Bangladesh, Bhutan, Brunei, Cambodia, China, Hong Kong, India, Indonesia, Laos, Malaysia, Maldives, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Republic of Korea, Singapore, Sri Lanka, Taiwan, Thailand, Timor-Leste, Vietnam

(Oceania)

Australia, Fiji, Kiribati, Marshall Islands, Micronesia, New Zealand, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu

(North America)

Canada, United States of America

(Latin America)

Antigua and Barbuda, Argentine, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, Uruguay, Venezuela

(Europe)

Albania, Andorra, Armenia, Austria, Azerbaijan, Belarus, Belgium,Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Cyprus, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kazakhstan, Kosovo, Kyrgyz Republic, Latvia, Liechtenstein, Lithuania, Luxemburg, Macedonia, Malta, Moldova, Monaco, Montenegro, the Netherlands, Norway, Poland, Portugal, Rumania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Tadzhikistan, Turkmenistan, Ukraine, United Kingdom, Uzbekistan, Vatican

(Middle East)

Afghanistan, Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Palestine, Oman, Qatar, Saudi Arabia, Turkey, United Arab Emirates

(Africa)

Algeria, Botswana, Cameroon, Chad, Republic of Congo, Djibouti, Egypt, Equatorial Ginea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Kenya, Madagascar, Mali, Mauritania, Morocco, Namibia, Niger, Nigeria, Rwanda, Senegal, South Africa, Sudan, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe

(International Organization)

ADB, AfDB, ASEAN, BSEC, CARICOM, CTBTO, Energy Charter Secretariat, EU, FAO, GECF, GEF, IAEA, ICPO, ICRC, IDB, IEA, IFRC, ILO, INCB, IOM, ISTC, ITSO, ITTO, ITU, MERCOSUR, NATO, OCHA, OECD, UNDAC, UNDP, UNEP, UNESCO, UNFPA, UN- HABITAT, UNHCR, UNICEF, UNV, UPU, World Bank, WCO, WFP, WHO, WTO

Source: http://www.mofa.go.jp/j_info/visit/incidents/index.html

Table B.1 shows the solution for another possibility of delivering the supply from RES to RED, where we want to deliver all the supply from RES to RED at once.

Table B.1 **Amount of drinking water delivered (m^3)**

K2	MaxGap (m^3)	TotalCost (km)	Total Excess Demand (m^3)		Total Excess Supply (m^3)		Routes	Amount of relief aid (Water) to be delivered (m^3)
			Original	Improved (Remaining)	Original	Improved (Remaining)		
50 ~ 70	282.49	3,270.38	823.12	751.97	71.15	0.00	6 → **2** 9 → 7 ↘ **4** 8 ↗	11.03 = **11.03** 37.94 + 15.73 + 6.45 + = **60.12**
80 ~ 110	244.55	6,115.88	823.12	751.97	71.15	0.00	6 → **2** 7 ↘ **4** 8 ↗ 9 → 10 → **11**	11.03 = **11.03** 15.73 + 6.45 + = **22.18** 37.94 + 0 = **37.94**
120 ~ 170	222.37	8,635.12	823.12	751.97	71.15	0.00	6 → **2** 7 ↘ 9 → 10 → **11** 8 ↗	11.03 = **11.03** 15.73 + 37.94 + 0 6.45 + = **60.12**
180 ~	**211.34**	**10,598.50**	**823.12**	**751.97**	**71.15**	**0.00**	6 → 7 ↘ 9 → 10 → 11 8 ↗	11.03 + 15.73 + 37.94 + 0 6.45 + = **71.15**

Source: Author's calculation.

From **Table B.1** we see that when the value of K_2 is small then the excess supply from RES are delivered only to the nearest RED, irrespective of the amount of the demand gap of RED. As we can see from the solution when $K_2 \leq 70$, excess supply from region 6 deliver to its closest neighbor, i.e. region 2, while excess supply from regions 7, 8, and 9 deliver to region 4. In which, we can notice that both region 2 and region 4 do not have the largest demand gap. And along with increasing the value of K_2, we can observe that there is a changing in delivery routes. When $K_2 \geq 180$, all the excess supply from RES are delivered to region 11, namely region that has the maximum demand gap, implies that it minimizes the maximum demand gap rather than minimizes the transportation cost.

Figure B.1 and **Figure B.2** depict the illustration for delivering drinking water from RES to RED for lower K_2 (i.e. K_2 = 50) and for higher K_2 (i.e. K_2 = 180), respectively. From **Figures B.1** and **B.2** we can clearly distinguish the routes to be taken for delivering the excess supply from RES to RED by choosing which one is more important, minimizing the transportation cost or minimizing the maximum demand gap.

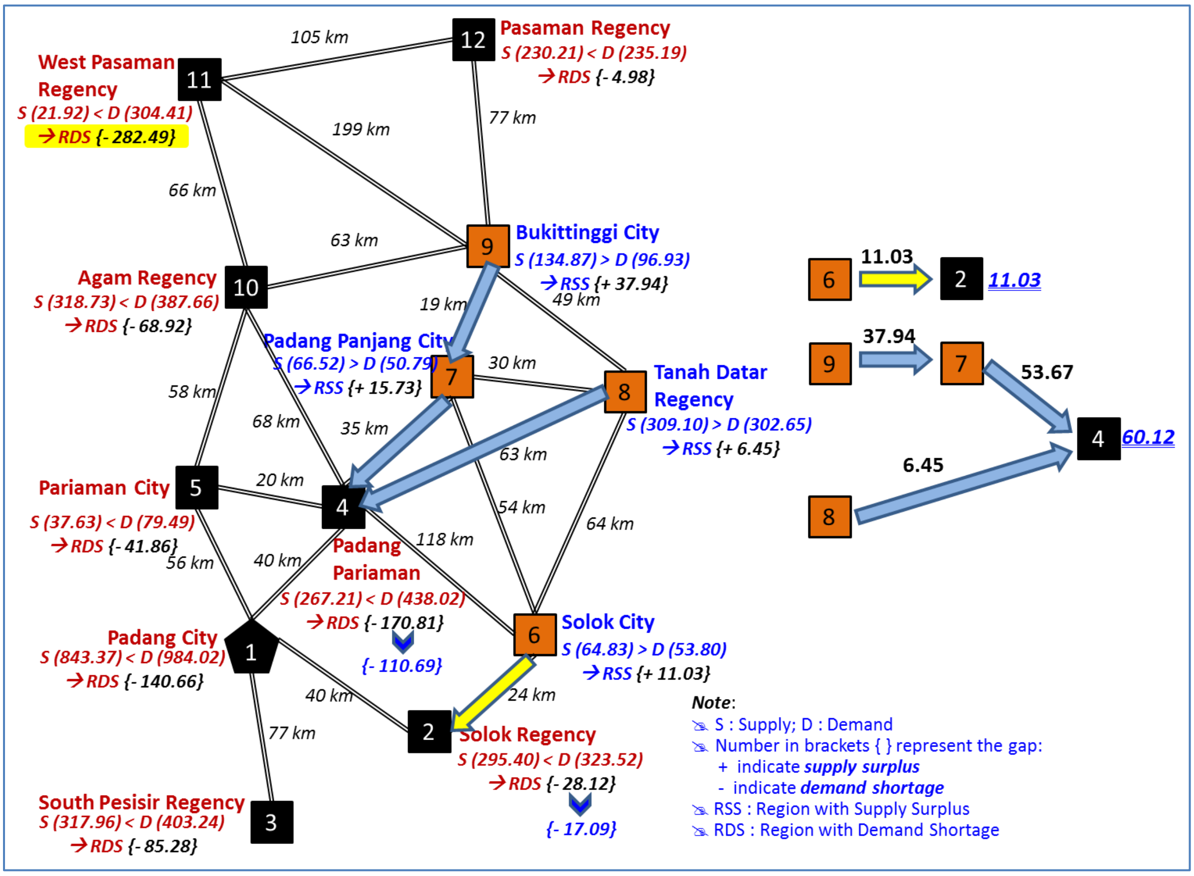


Figure B.1 **Illustration for delivering drinking water from RES to RED (K_2 = 50)**

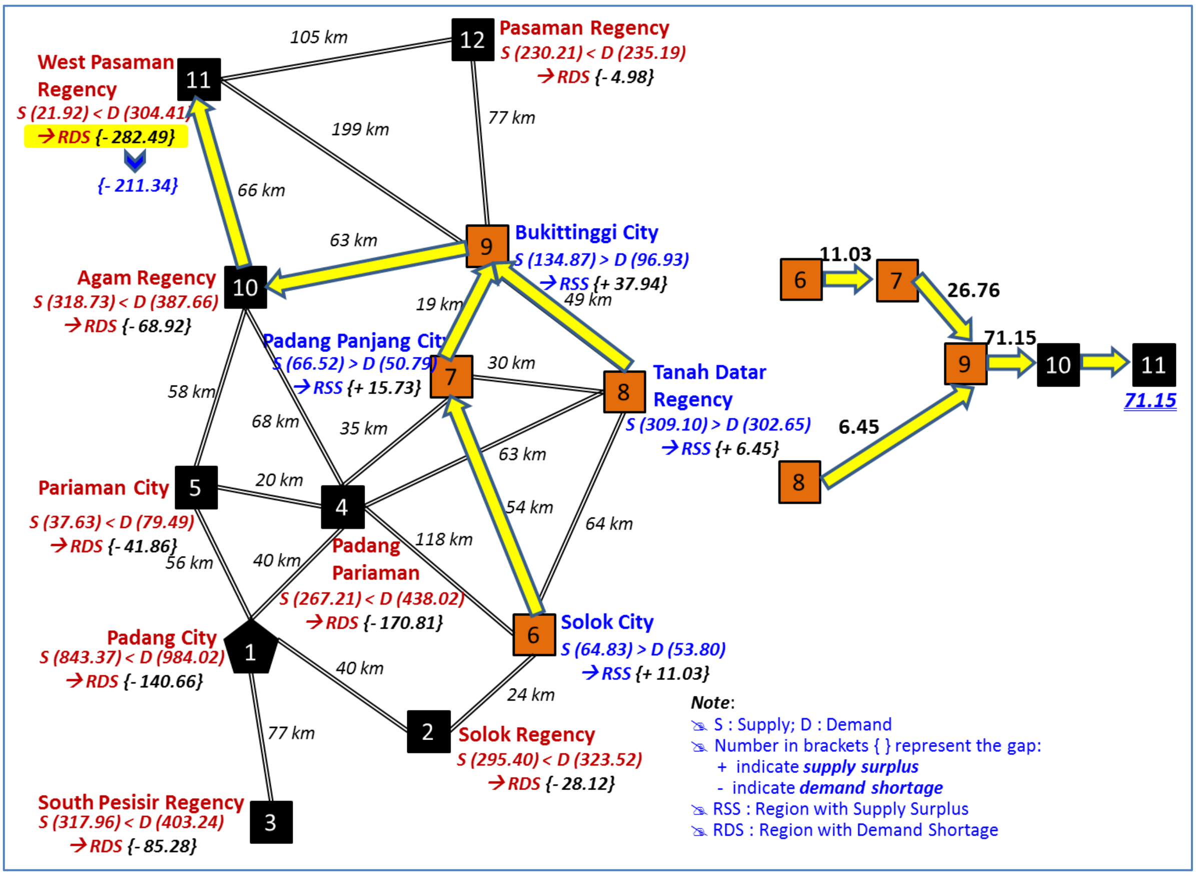


Figure B.2 **Illustration for delivering drinking water from RES to RED (K_2 = 180)**

Table C.1 **Amount of food delivered (Ton)**

K2	MaxGap (Ton)	TotalCost (km)	Total Excess Demand (Ton)		Total Excess Supply (Ton)		Routes	Amount of relief aid (Food) to be delivered (Ton)
			Original	Improved (Remaining)	Original	Improved (Remaining)		
100	1,873.24	3,774.40	3,593.04	3,539.57	808.01	754.54	2→ 1 6 7 → 4 9 8	17.95 + 0 + 5.29 + 0 = **53.47** 4.1 + 26.13 +
110	1,873.24	3,774.40	3,593.04	3,539.57	808.01	754.54	2→ 1 6 7 → 4 9 8	17.95 + 0 + 5.29 + 0 = **53.47** 4.1 + 26.13 +
120 ~	**1,118.70**	**92,055.60**	**3,593.04**	**2,785.03**	**808.01**	**0.00**	2 1 3 4 6 7 9 8	17.95 + 0 + 754.54 + **= 808.01** 5.29 + 0 + 4.1 + 26.13 +

Table C.2 **Amount of medicine delivered (Ton)**

K2	MaxGap (Ton)	TotalCost (km)	Total Excess Demand (Ton)		Total Excess Supply (Ton)		Routes	Amount of relief aid (Medicine) to be delivered (Ton)
			Original	Improved (Remaining)	Original	Improved (Remaining)		
100	56.26	692.39	150.78	139.19	53.49	41.90	9 → 7 4 8	3.14 + 0.34 + **= 11.59** 8.11 +
110	53.38	994.98	150.78	133.43	53.49	36.14	2 → **1** 9 → 7 4 8 10	2.88 **= 2.88** 3.14 + 0.34 + **= 14.47** 9.8 + 1.19 +
120 ~ 130	49.71	1,435.38	150.78	126.09	53.49	28.80	2 → 1 - -> **1** 9 → 7 4 8 10	10.22 - 3.67 **= 6.55** 3.67 + 3.14 + 0.34 + **= 18.14** 9.8 + 1.19 +
140 ~ 190	48.84	1,555.44	150.78	124.35	53.49	27.06	2 → 1 - -> **1** 6 7 9 4 8 10	10.22 - 2.8 **= 7.42** 2.8 + 1.74 + 0.34 + 3.14 + **= 19.01** 9.8 + 1.19 +
200 ~ 220	43.165	2,656.39	150.78	113.00	53.49	15.71	2 1 - -> **1** 3 6 7 9 4 8 10	10.22 + - 8.475 **= 13.095** 11.35 + 8.475 + 1.74 + 0.34 + 3.14 + **= 24.685** 9.8 + 1.19 +
230 ~	**35.31**	**4,424.50**	**150.78**	**97.29**	**53.49**	**0.00**	2 1 - -> **1** 3 6 7 12 → 9 4 8 11 → 10	10.22 + - 0.62 **= 20.95** 11.35 + 0.62 + 1.74 + 0.34 + 7.61 + 3.14 + **= 32.54** 9.8 + 8.1 + 1.19 +

Source: Author's calculation.

Tables D.1 – D.4 present the solution for the scheduling as well as the number of vehicles necessary for delivering drinking water from the main supply center (SC) to RED which still have remaining demand shortage for drinking water at various values of K_2, namely from the lowest to the highest value of K_2, respectively.

Table D.1 **Scheduling and the number of vehicles necessary for delivering drinking water (units) ($K_2 \leq 70$)**

Region (One Batch Time, Cars)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
2(5,3) :	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3(8,15) :	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4(5,19) :	7	7	7	7	7	7	7	7	7	7	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5(6,7) :	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10(10,12) :	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11(14,48) :	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	0	0	0	0	0	0
12(14,1) :	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total:	39	39	39	39	39	39	39	39	39	39	37	37	35	35	34	28	22	22	21	21	21	21	21	21	20	20	20	20	20	20	16	16	16	16	16	16	16	16	16	16	16	16	0	0	0	0	0	0

Source: Author's calculation.

Table D.2 **Scheduling and the number of vehicles necessary for delivering drinking water (units) (K_2 = 80 – 110)**

Region (One Batch Time, Cars)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
2(5,3) :	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3(8,15) :	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4(5,25) :	11	11	11	11	11	11	11	11	11	11	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5(6,7) :	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10(10,12) :	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11(14,41) :	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	13	13	13	13	13	13	13	13	13	13	13	13	13	13	0	0	0	0	0	0
12(14,1) :	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total:	39	39	39	39	39	39	39	39	39	39	31	31	29	29	28	24	24	24	23	23	23	23	23	23	18	18	18	18	17	17	13	13	13	13	13	13	13	13	13	13	13	13	0	0	0	0	0	0

Source: Author's calculation.

Table D.3 **Scheduling and the number of vehicles necessary for delivering drinking water (units) (K_2 = 120 – 170)**

Region (One Batch Time, Cars)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
2(5,3) :	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3(8,15) :	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4(5,29) :	12	12	12	12	12	12	12	12	12	12	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5(6,7) :	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10(10,12) :	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11(14,38) :	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	12	12	12	12	12	12	12	12	12	12	12	12	12	12	0	0	0	0	0	0
12(14,1) :	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total:	39	39	39	39	39	39	39	39	39	39	32	32	30	30	29	23	23	23	22	22	22	22	22	22	17	17	17	17	16	16	12	12	12	12	12	12	12	12	12	12	12	12	0	0	0	0	0	0

Source: Author's calculation.

Table D.4 **Scheduling and the number of vehicles necessary for delivering drinking water (units) ($K_2 \geq 180$)**

Region (One Batch Time, Cars)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2(5,5) :	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0
3(8,15) :	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
4(5,29) :	12	12	12	12	12	12	12	12	12	12	5	5	5	5	5	0	0	0	0	0	0	0	0	0
5(6,7) :	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	0	0	0	0	0	0
6(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10(10,12) :	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
11(14,36) :	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
12(14,1) :	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Total:	**39**	**39**	**39**	**39**	**39**	**39**	**39**	**39**	**39**	**39**	**31**	**31**	**29**	**29**	**28**	**22**	**22**	**22**	**21**	**21**	**21**	**21**	**21**	**21**

Region (One Batch Time, Cars)	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
2(5,5) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3(8,15) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4(5,29) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5(6,7) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10(10,12) :	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11(14,36) :	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	0	0	0	0	0	0
12(14,1) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total:	**16**	**16**	**16**	**16**	**16**	**16**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**0**	**0**	**0**	**0**	**0**	**0**

Source: Author's calculation.

Table E.1 – E.6 present the solutions for delivering food and medicine from the main supply center (SC) to RED which still have remaining demand shortage for drinking water at various values of K_2

Table E.1 **Scheduling and the number of vehicles necessary for delivering food (units) (K_2 = 0 - 30)**

Region (One Batch Time, Cars)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
2(5,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3(8,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4(5,128) :	27	27	27	27	27	27	27	27	27	27	26	26	26	26	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5(6,16) :	8	8	8	8	8	8	8	8	8	8	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7(7,0) :	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10(10,41) :	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	13	13	13	13	13	13	13	13	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11(14,15) :	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	0	0	0	0	0	0
12(14,1) :	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total:	**56**	**56**	**56**	**56**	**56**	**56**	**56**	**55**	**55**	**55**	**54**	**54**	**46**	**46**	**45**	**19**	**19**	**19**	**19**	**19**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**0**	**0**	**0**	**0**	**0**	**0**

Source: Author's calculation.

Table E.2 **Scheduling and the number of vehicles necessary for delivering food (units) ($K_2 \geq 40$)**

Region (One Batch Time, Cars)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
2(5,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3(8,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4(5,80) :	27	27	27	27	27	27	27	27	27	27	26	26	26	26	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5(6,16) :	8	8	8	8	8	8	8	8	8	8	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7(7,1) :	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10(10,41) :	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	13	13	13	13	13	13	13	13	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11(14,15) :	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	0	0	0	0	0	0
12(14,1) :	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total:	**56**	**56**	**56**	**56**	**56**	**56**	**56**	**55**	**55**	**55**	**54**	**54**	**46**	**46**	**45**	**19**	**19**	**19**	**19**	**19**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**0**	**0**	**0**	**0**	**0**	**0**

Source: Author's calculation.

Table E.3 **Scheduling and the number of vehicles necessary for delivering medicine (units) (K_2 = 0 - 10)**

Region (One Batch Time, Cars)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
2(5,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3(8,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4(5,4) :	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5(6,2) :	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10(10,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11(14,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12(14,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total:	**6**	**6**	**6**	**6**	**6**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Source: Author's calculation.

Table E.4 **Scheduling and the number of vehicles necessary for delivering medicine (units) (K_2 = 20)**

Region (One Batch Time, Cars)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
2(5,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3(8,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4(5,3) :	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5(6,2) :	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10(10,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11(14,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12(14,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total:	5	5	5	5	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Author's calculation.

Table E.5 **Scheduling and the number of vehicles necessary for delivering medicine (units) (K_2 = 30 - 40)**

Region (One Batch Time, Cars)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
2(5,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3(8,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4(5,3) :	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5(6,2) :	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10(10,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11(14,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12(14,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total:	5	5	5	5	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Author's calculation.

Table E.6 **Scheduling and the number of vehicles necessary for delivering medicine (units) ($K_2 \geq 50$)**

Region (One Batch Time, Cars)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
2(5,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3(8,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4(5,3) :	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5(6,2) :	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7(7,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9(9,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10(10,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11(14,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12(14,0) :	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total:	5	5	5	5	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Author's calculation.