# 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.