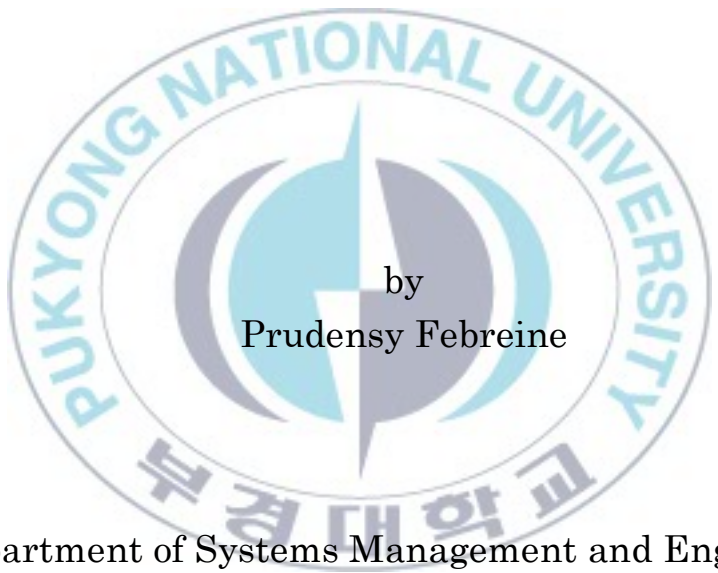
Thesis for the Degree of Master of Engineering

A Stock Pre-positioning Model to Maximize the Total Expected Relief Demand of Disaster Areas



by
Prudensy Febreine

Department of Systems Management and Engineering
The Graduate School
Pukyong National University

February 2012

A Stock Pre-positioning Model to Maximize the Total Expected Relief Demand of Disaster Areas

Advisor: Prof. Woon-Seek Lee

by

Prudensy Febreine

A thesis submitted in partial fulfillment of the requirements

for the degree of

Master of Engineering

In Department of Systems Management and Engineering,

The Graduate School, Pukyong National University

February 2012

A Stock Pre-positioning Model to Maximize the Total Expected Relief Demand of Disaster Areas

A thesis

by

Prudensy Febreine

Approved by:

_____
(Prof. Woon-Seek Lee)

_____ _____
(Prof. Pyung-Hoi Koo) (Prof. Byung Soo Kim)

February 24, 2012

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

Disaster Management that covers natural disasters such as earthquakes, tsunamis, floods, landslides, volcanic eruptions, or typhoons is required to identify hazard prone and formulate actions that should be prioritized. Ordinarily, natural disasters that come along with uncertainty factors are very difficult to predict. Some of them are even nearly impossible to predict. They come suddenly and without warning.

On 26 December 2004, an earthquake with magnitude 9.1 *Mw* (moment magnitude scale) triggered a series of devastating tsunamis and killing over 225,000 people in eleven countries, including Indonesia, Sri Lanka, India and Thailand. This natural disaster, known as 2004 Indian Ocean Tsunami, becomes one of the deadliest earthquakes ever recorded since modern record-keeping began in 1900.

Six years later, on 12 January 2010, people in Haiti was shocked by an earthquake with magnitude 7.0 *Mw* followed by at least 52 aftershocks for the next ten days measuring 4.5 *Mw* or greater. The earthquake killed about 316,000 people and made another 1,000,000 people homeless.

Just by a year later, a 9.0 Mw undersea megathrust earthquake that occurred on 11 March 2011 had devastated the eastern part of Japan. The earthquake also triggered powerful tsunami waves and caused the death of more than 15,000 people, and destruction of infrastructure, including a number of nuclear accidents at three reactors in the Fukushima nuclear power plant. The disaster has led the Japanese governments to deal with the toughest and the most difficult crisis in recent years.

The experience of 2004 Indian Ocean Tsunami, 2010 Haiti earthquake, and 2011 Tohoku earthquake, further demonstrates the importance of disaster management.

Altay and Green [1] mentioned that there were four programmatic phases in disaster management: mitigation, preparedness, response, and recovery. Each phase carried their own issues, including zoning and land use control to prevent occupation of high hazard area, evacuation of threatened population, recruiting personnel for the emergency services, and financial assistance to individuals and governments.

One of the critical studies to perform preparedness phase in disaster management is pre-positioning theory. Pre-positioning involves preparing critical relief supplies in strategic locations and determining the amount of demand to be released in disaster areas.

According to Beamon [4], many issues were restrict and need to be focused in pre-positioning stage; including budget limitation, limited number of distribution centers and limited capacity for each distribution center. In addition, the demand is uncertain. Once the disaster happens in one location, demand is requested, and demand must be transported efficiently into the disaster area. Because in disaster relief case, the demands are lumpy and occur suddenly, such that the locations are completely unknown until the demand occurs. In this study, we determined these issues in stock pre-positioning.

The work of Balcik and Beamon [3] integrated facility location and inventory decisions. Their model determined the number and locations of distribution centers in a relief network and the amount of relief supplies to be stocked at each distribution center to meet the needs of people affected by the disasters. They considered multiple item types, and captured budgetary constraints

and capacity restriction of distribution centers. They also provided the simulation of pre- and post-disaster relief funding on relief system's performance.

In particular, this thesis focused on stock pre-positioning to support an emergency disaster relief response against the event of earthquake by carefully considering the response time needed for each existing distribution centre to serve one or more disaster areas. In this study, the distribution centers have been established by the governments and each distribution center is located in a single disaster area. In order to obtain the maximum number of inventory stocked in each distribution center, a new variable of maximum response time limit is introduced to the proposed model.

Since the distribution centers have been established, the service area for each distribution center still remains uncertain. Based on the maximum response time limit, each distribution center is assigned to serve only for disaster areas that located between the maximum limit of the expected response time. The results simultaneously determine the decisions of the amount of supplies to be stocked in each distribution center which has been assigned to serve the specific disaster areas. An adjustment of the general model to be used in the real system is provided.

In this thesis, the proposed model is applied to Indonesia as one of the earthquake-prone countries in Asia. Finally, a sensitivity analysis is performed by changing the important parameters such as response time, budget and capacity of each distribution center. The objective of this study is to support an emergency disaster relief response against the event of earthquake by maximizing the total expected relief demand covered by the existing distribution centers.

The remaining of the thesis is comprised as follows: In chapter 2, a literature survey is introduced on the research area of disaster management and humanitarian logistics. In chapter 3, a mathematical model is formulated and

related data is constructed based on Indonesian Cases. In chapter 4, computational results are illustrated by performing sensitivity analysis on various test problems. Finally, in chapter 5 the conclusion and future research areas are remarked.

Chapter 2. Literature Survey

In this chapter, the related literatures with disaster management and humanitarian logistics are introduced. In humanitarian logistics, two important topics such as the location of distribution centers and the stock pre-positioning are classified and the related studies for the topics are surveyed, respectively.

2.2 Disaster management

Disaster management has become key priorities for the government of disaster-prone countries in order to integrate all disaster management policies and programs. Also it has become a great issue both in local and central government for years.

Disaster management covers large area of disasters classification. Amin and Goldstein [2] mentioned that disasters are classified to natural disasters, technological disasters, or complex emergencies. The last also called man-made disaster which includes civil wars and conflicts. The classification refers to the immediate trigger: a natural phenomenon or hazard (biological, geological, or climatic) and technological accident, or conflict. Figure 1 describes the disaster classification.

Disaster Classification	
Natural Disaster • Earthquake • Landslide • Tsunami • Volcanic eruption • Flood • Typhoon • another biological, geological, or climatic phenomenon	**Man-Made Disaster** • Civil war • Conflict • Technological accident

Figure 1. Disaster classification

They also mentioned that a cycle in disaster response consists of a succession of clearly distinct phases, from prevention to preparedness, early warning, impact, and relief, recovery, and reconstruction. This cycle consists of four phases of disaster management. Meanwhile, Altay and Green [1] mentioned about four programmatic phases of comprehensive emergency management: mitigation, preparedness, response, and recovery. The two standpoints of four phases of disaster management are described in Figure 2.

Four phases of disaster management:	
Amin and Goldstein (2008) **1) Risk reduction** Minimizing the vulnerability and the risk of disaster throughout a society and avoiding (prevention) or limiting (mitigation and preparedness) the adverse impacts of hazards within a broad con-text of sustainable development. Early warning means provision of timely and effective information that allows individuals exposed to a hazard to take action to avoid their risk and prepare for effective response. **2) Relief** Provision of assistance or intervention during or immediately after a disaster to save and protect lives and meet the basic subsistence needs of people affected by the disaster. **3) Early recovery** Decisions and actions taken after a disaster with a view to restoring or improving the pre-disaster living conditions of the stricken community basic facilities (for example, health and education) **4) Recovery and reconstruction** Actions taken after a disaster (rebuild infrastructure, livelihoods, other basic needs)	*Altay and Green (2006)* **1) Mitigation** Zoning and land use controls, barrier construction to deflect disaster forces, active preventive measures, controls on rebuilding after events, risk analysis. **2) Preparedness** Recruiting personnel, emergency planning, training response personnel and concerned citizens, budgeting for and acquiring vehicles and equipment, maintaining emergency supplies, construction of an emergency operations center, development of communications systems. **3) Response** Activating the emergency operations plan, activating the emergency operations center, evacuation of threatened populations, opening of shelters and provision of mass care, emergency rescue and medical care, urban search and rescue, emergency infrastructure, fatality management **4) Recovery** Disaster debris cleanup, financial assistance to individuals and governments, rebuilding key facilities, sustained mass care for displaced human and animal populations, reburial of displaced human remains, full restoration of lifeline services, mental health and pastoral care

Figure 2. The two standpoints of four phases of disaster management

Based on Figure 2, the differences between two standpoints lie on the preparedness phase. Altay and Green [1] emphasized the preparedness phase in the second phase between mitigation and response phase. Meanwhile, Amin and Goldstein [2] were focused on the relief or live saving (search and rescue, medical care, basic needs) and included preparedness in the risk reduction (first phase). The other phases are quite similar, which is ended by recovery and reconstruction phase.

One of the important issues in disaster management is the performance of the four phases. In most cases, the execution of each phase is still not optimal. The governments, citizens, or even non-government organizations (NGO's) have not been prepared to deal with disasters. This issue increased the number of victims and improved the numbers of human lives in stake.

Each phase has its own difficulties. Mitigation (risk reduction) and preparedness phase need to be planned and programmed carefully while response and recovery phase need to be done in a short span of time. It is important to develop disaster rapid response teams that can response soon after the disasters occurred.

Tufekci and Wallace [21] suggested that emergency response efforts consist of two stages; pre-event and post-event response. Pre-event tasks include predicting and analyzing potential dangers and developing necessary action plans for mitigation. Post-event response starts while the disaster is still in progress. This opinion narrows the four phases of disaster management (see Figure 2). Figure 3 classifies the four phases of disaster management into the concept of two stages of pre- and post-event response.

Classification of pre- and post event response	
Pre-event response - Mitigation (risk reduction) - Preparedness	**Post-event response** - Response - Recovery and reconstruction

Figure 3. Classification of the two stages of pre- and post-event response

Preparedness stage, one of the two stages in pre-event response classification, recently has become important in the field of study and research. Wassenhove [22] mentioned the preparedness consists of five key elements that have to be in place to produce effective results. These in turn lead to effective disaster management. Figure 4 describes the five key elements to produce effective results in disaster management.

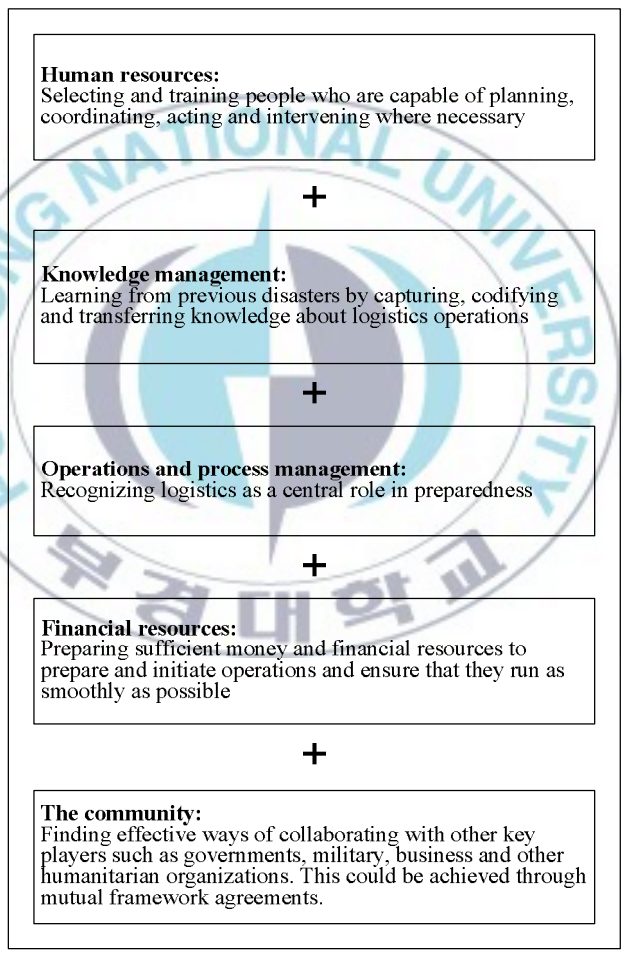


Figure 4. Five key elements to produce effective results in disaster management

2.2 Humanitarian Logistics

The term of logistics have been widely used; humanitarian logistics or emergency logistics, military logistics, and business logistics. Each of them has their own concept, definition, and focus.

Wassenhove [22] mentioned that for humanitarians, logistics is the processes and systems involved in mobilizing people, resources, skills, and knowledge to help vulnerable people affected by disaster. In general, Wassenhove [22] remarked that logistics from a military view has primarily been oriented to distribution and system or product support, and has included the elements of maintenance planning, personnel, supply support, support equipment, technical data, training and training devices, computer resources support, facilities, packaging, handling, storage, transportation, and reliability, and maintainability interface. There are two different types of logistics; one focuses on reducing the number of people affected by disaster, and the other focuses on the distribution of supply, facilities, personnel, and so on.

In the industrial or commercial sector, logistics, often called business logistics or industrial logistics, has been defined to include such activities as material flow, product distribution, transportation, purchasing and inventory control, warehousing, customer service, and so on. Generally, the business or industrial logistics focuses on maximizing the profits related in the related activities.

Blanchard [6] and Wassenhove [22] mentioned although the definition is somewhat different, the term logistics is applicable throughout both the private and public sectors, and the fact that logistics includes the planning and preparedness, design, procurement, transportation, inventory, warehousing, distribution, and recipient satisfaction. This statement is similar with the statement

made by Bowersox and Closs [7]. The authors mentioned that logistics involves the integration of information, transportation, inventory, and a variety of stimulating jobs.

The application of logistics research and practice has been very much focus on business context. Meanwhile, another important application area of logistics in the context of humanitarian aid only occupied a small portion in the logistics research.

Based on a workshop with humanitarian organizations, Thomas and Mizushima [19] defined humanitarian logistics as the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of meeting the end beneficiary's requirements.

Oloruntoba and Grey [15] introduced that humanitarian logistics concerns aid after natural and man-made disasters as well as in complex emergencies including war and conflict situations. It is undertaken in a context characterized as clearly unpredictable, turbulent and requiring flexibility. Meanwhile, Kovács and Spens [13] mentioned that humanitarian logistics deals with disasters which range from earthquakes, tsunamis, hurricanes, epidemics, droughts, famines, terrorist attacks, and war situations to a combination of several disasters which may occur simultaneously.

Figure 5 illustrates a typical humanitarian supply chain. The added circle indicates the role of international and local NGOs in humanitarian supply chain. Those two factors contribute the complexity in performing an effective emergency logistics. The complexity increases when the government has lack of information and still not ready in performing emergency response.

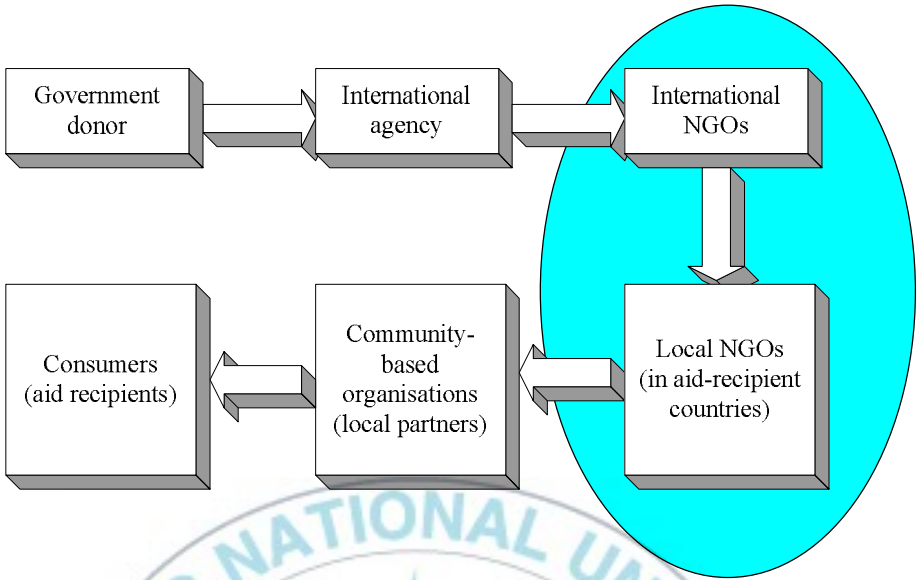


Figure 5. A typical humanitarian supply chain [15]

Basically, humanitarian supply chain is very much different from a commercial supply chain. In Figure 6, Beamon [4] classified the two types of supply chains: commercial supply chain and humanitarian relief chain. From the basic concepts of the two types of supply chains, they are different from each other.

The commercial supply chain focuses on the deployment of products as its demand, while the humanitarian relief chain focuses on the deployment of emergency supplies and the relief of the people in disaster area. The major goal of humanitarian supply chain is to minimize the loss of life. In this case, the profit is need to be the number of people who survived the disaster.

	Commercial Supply Chain	Humanitarian Relief Chain
Demand Pattern	Relatively stable, predictable demand patterns. Demands occur from fixed locations in set quantities.	Demand is generated from random events that are unpredictable in terms of timing, location, type, and size. Demand requirements are estimated after they are needed, based on an assessment of disaster characteristics.
Lead Time	Lead time determined by the supplier-manufacturer-DC-retailer chain.	Approximately zero lead times requirements (zero time between the occurrence of the demand and the need for the demand), but the actual lead time is still determined by the chain of material flow.
Distribution Network Configuration	Well-defined methods for determining the number and locations of distribution centers.	Challenging due to the nature of the unknowns (locations, type and size of events, politics, and culture), and "last mile" considerations.
Inventory Control	Utilizes well-defined methods for determining inventory levels based on lead time, demand and target customer service levels.	Inventory control is challenging due to the high variations in lead times, demands, and demand locations.
Information system	Generally well-defined, using advanced technology.	Information is often unreliable, incomplete or non-existent.
Strategic Goals	Typically: to produce high quality products at low cost to maximize profitability and achieve high customer satisfaction.	Minimize loss of life and alleviate suffering.
Performance Measurement System	Traditionally: focused on resource performance measures, such as maximizing profit or minimizing costs.	Primary focus on output performance measures, such as the time required to respond to a disaster or ability to meet the needs of the disaster (customer satisfaction).
What is "Demand"?	Products	Supplies and people.

Figure 6. Commercial Supply Chains vs. Humanitarian Relief Chains [4]

Research area of humanitarian logistics is unique and also very complex at the same time. According to Beamon [4], the dominating characteristics that bring additional complexity and unique challenges to humanitarian supply chains are as follows:

a. Unpredictability of demand, in terms of timing, location, type, and size
b. Suddenly-occurring demand in very large amounts and short lead times for a wide variety of supplies
c. High stakes associated with adequate and timely delivery
d. Lack of resources (supply, people, technology, transportation capacity, and money)

Recently, the study of humanitarian logistics as a part of disaster management received much more attention and become more interesting. Most authors concern about one element of humanitarian logistics, i.e., natural disaster; earthquake, hurricane, flood, and so on.

Tovia [20] built an emergency response model (ERM) that can be used by offices of emergency preparedness to evaluate response capabilities, to assess the logistics challenges in the event of natural disaster, specifically hurricane, and to perform what-if analysis on the threat of a weather disturbance system. Chang *et al.* [8] applied the data processing and network analysis functions of the geographic information system to estimate the possible locations of rescue demand points and the required amount of rescue equipment for flood emergency logistics.

Balcik and Beamon [3] developed an interesting model that integrates facility location and inventory decisions. Their model determines the number and locations of distribution centers in a relief network and the amount of relief supplies to be stocked at each distribution center to meet the needs of people affected by the disasters. They considered multiple item types, and captured budgetary constraints and capacity restrictions of distribution centers. They also provide the simulation of pre- and post-disaster relief funding on relief system's performance.

In order to perform an effective humanitarian logistics, the determination of distribution center location and stock pre-positioning are critical. There are some issues that need to be considered to determine locations of distribution centers and stock pre-positioning.

2.2.1 Location of distribution centers

Coyle *et al.* [9] mentioned that a warehouse or distribution center is a point in the logistics system where a firm stores or holds raw materials, semi-finished goods, or finished goods during varying period of time. Warehouse management involves a number of important decisions, including number, size, stock, and location, that is, how many, what size, what product, and where. One of

the most important tasks is to decide how many warehouses to have in the system.

In the term of humanitarian logistics, one of the constraints in deciding the number and location of distribution centers are the concept of time. This means that a distribution center should be able to send items to the demand point within a certain period by considering the availability of budgets and vehicles. Figure 7 illustrates the concept of time constraint.

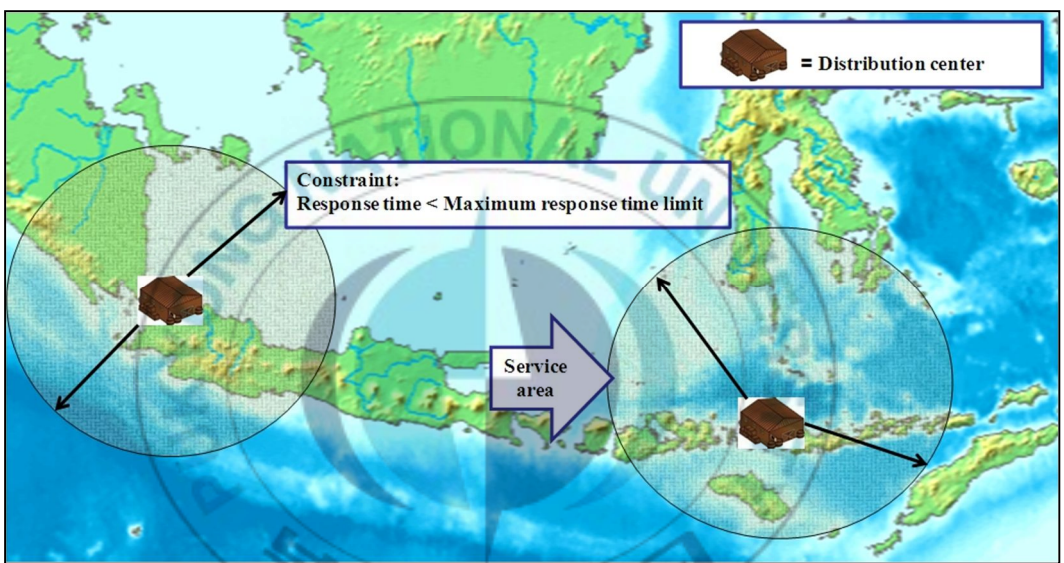


Figure 7. Time constraint

According to Coyle *et.al.* [9], increasing the number of distribution centers in a logistics system affects important physical distribution costs. As the number of distribution center increases, transportation cost and the cost of lost sales decrease, whereas inventory cost and warehousing cost increase. Figure 8 illustrates total cost versus the number of distribution centers

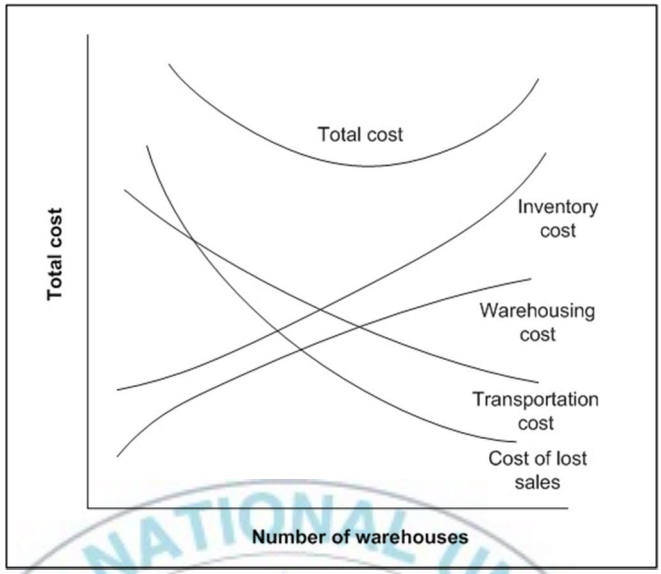


Figure 8. Total cost vs. the number of distribution centers [9]

In order to support stock pre-positioning, it is very important to know the steps in determining the location of distribution centers. Hale and Moberg [11] suggested that emergency resources need to be located in a manner as to not be vulnerable to attack. But, they need to be close to the areas to which they are assigned to serve. Therefore, it may fall in dilemma: how best to locate an emergency resource within the supply chain to best serve m areas without being vulnerable itself, where m means the number of areas to be served.

There are 4 important steps that will lead to the selection of a number of emergency resource locations that provide quick access to critical resources:

Step 1. Identify the emergency resources needed at each secure location

Critical documents, such as contact lists of key managers, government agencies, and non-profit organizations, area maps, and other essential checklists for managers, are stored in a safe and secure location. In addition, other critical items such as medical supplies, generators, water, and back-up communications, that should be available during

emergencies.

Step 2. Identify all critical facilities within the supply chain

The second step in the process is to identify the locations within the supply chain that may access to emergency resources. These decisions will vary by the supply chain because of differences in channel design, communications systems, sourcing decisions, and inventory management strategies.

Step 3. Set maximum response time goals for access to emergency resources and minimum distances secure site storage areas must be placed from supply chain facilities

Because the storage of emergency resources will be off-site and each secure location may service multiple facilities, a decision must be made within the maximum time that should take any facility in the supply chain to gain access to emergency resources. This constraint is important because it will be a primary factor in determining how many emergency resource storage areas will be needed to cover the whole supply chain. Managers must balance the desire to minimize costs that provides reasonably quick access to the critical materials stored at each location.

Step 4. Use the proposed decision model to identify the number and approximate location of emergency resource storage facilities

The set cover location problem is a prominent area of research within the location science community and a mature body of research exists on set cover location models. In general, the use of a set cover location model would necessitate the use of some existing but very complex solution methods for the associated set cover location problem.

2.2.2 Stock pre-positioning

After the location of each distribution center has been decided, the next step is to determine the maximum amount of inventory to be stocked in each distribution center. Hale and Moberg [11] mentioned that rather than waiting passively for a situation of crisis to occur somewhere in the world to launch humanitarian operations, it is better to show pro-activity by mobilizing supplies or other material and non-material resources in anticipation. Therefore, it is necessary to take the location of these resource storage facilities into account, as poor location increases the likely hood of a longer reaction time and would also have a negative impact on the implementation of humanitarian aid.

Balcik and Beamon [3] defined that after a disaster occurs, demand for aid supplies will likely change over time; some items are needed immediately at the earliest stages of relief operations, while other items can be safely supplied during later stages.

Types of pre-positioned stocks are various and are chosen carefully to meet the immediate needs of those affected. Figure 9 exhibits photographs of relevant inventory considered within the scope of this research.

Figure 9. Photographs of humanitarian consumable and non-consumable goods

The items are divided into two types: 1) food items (e.g. rice, ready-to-eat meals, and water), and 2) non-food items (e.g. tents, blankets, and medical supplies).

Pre-positioning critical relief supplies in strategic locations around the world is a strategy recently implemented by some humanitarian relief organizations to improve their capacities in delivering sufficient relief aid within a relatively short timeframe. According to Balcik and Beamon [3], although pre-positioning increases the ability of relief organizations to mobilize relief supplies and deliver aid quickly, it can be financially prohibitive. As such, only a few relief organizations can support the expense of operating international distribution centers to store and distribute relief supplies. In stock pre-positioning, there are some constraints that need to be considered. Budget availability and capacity of each distribution center are some of the constraints. The amount of inventory to be stocked will depend on these constraints.

Beamon [4] identified that the general flow of resources to the affected areas coincides with the four main phases of disaster relief: (1) assessment: minimal resources are required to identify what is needed, (2) deployment: resource requirements ramp up to meet the needs, (3) sustainment: operations are sustained for a period of time, and (4) reconfiguration: operations are reduced, then terminated. Figure 10 shows the four phases of disaster relief. The added circle indicates the phases of the process that are most time-sensitive. Reducing delivery time in this phase will significantly affect the lives of many people threatened by the disaster. This initial phase is the aim of pre-positioning in this study.

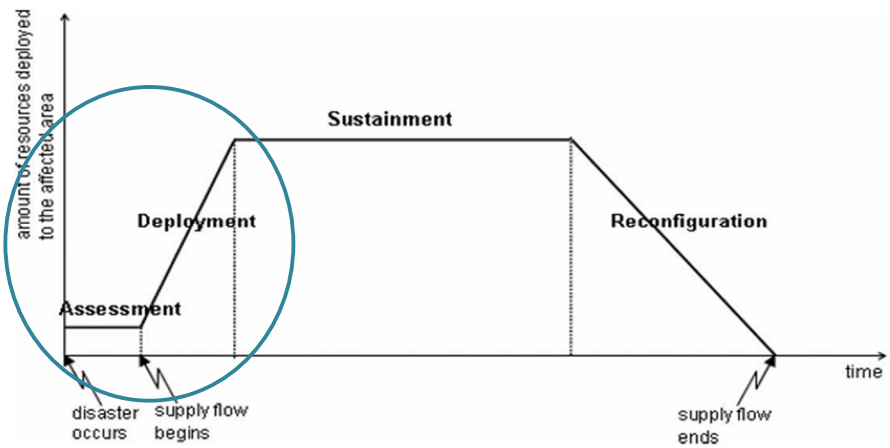


Figure 10. Relief mission life cycle (modified) [3]

In this thesis, the stock pre-positioning is proposed to support an emergency disaster relief response against the event of earthquake dealing with the response time for each existing distribution center to serve one or more disaster areas in Indonesia. Tables 1 and 2 shows the related literatures in the disaster management and the humanitarian logistics and the contributions of this thesis compared with the related literatures.

Table 1. Research area related to disaster management and humanitarian logistics

No	Author(s)	Year	Research Area														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Benita M. Beamon and Stephen A. Kotleba	2006	*	*		*						*					
2	Mei Shiang Chang, Ya Ling Tseng, and Jing Wen Cheng	2007	*		*	*				*	*		*				*
3	Kaan Ozbay and E.E Ozguven	2007	*		*	*						*					
4	Wei Yi and Linet Ozdamar	2007	*		*		*							*		*	
5	F. Tovia	2007	*		*		*									*	
6	B. Balcik and B.M. Beamon	2008	*		*	*				*	*					*	
7	Samuel Ratick, Brian Meacham, and Yuko Aoyama	2008	*		*	*		*									*
8	Aline Gatignon, Luk Van Wassenhove, and Aurelie Charles	2010			*										*		
9	M.T Ortuno, G. Tirado, and B. Vitoriano	2010	*	*					*								*
	This thesis	**2011**	*		*	*					*						*

Table 2. Definition of research areas

No	Definitions
1	Build an emergency response model
2	Focus on natural and man-made disaster
3	Focus on natural disaster
4	Focus on preparedness stage
5	Focus on evacuation stage
6	Focus on locating backup facilities
7	Focus on delivering the planned quantity of goods
8	Focus on determining the number and locations of distribution centres in a relief network
9	Focus on determining the amount of relief supplies to be stocked at each distribution centre
10	Focus on determining optimal order quantities, reorder points, and safety stocks
11	Apply data processing and network analysis
12	Build a location-routing model
13	Evaluate the decentralized supply chain's performance
14	Provide an illustration of the model
15	Apply the model into real system

Chapter 3. Model Formulation and Data Construction

3.1 Model Formulation

In this model, each distribution center is located in a single disaster area. Each distribution center can provide service in one or more disaster areas. Therefore, it is therefore very important to make the right decision in determining the service area for each distribution center. The decision of optimal supplies to be stocked in each distribution center will depend on the service area. In the model, it assumes that the earthquake will not occur at the same time in multiple disaster areas.

Data set:

i = disaster area;

j = distribution center;

J^i = distribution center j that provide service in disaster area i;

k = item type

Parameters:

T_{ij} expected time to satisfy relief demand in disaster area i from distribution center j (hour)

δ_i maximum response time limit to perform emergency response in disaster area i (hour)

P_i probability of occurrence of earthquake in disaster area i

d_{ik} expected demand for item type k in disaster area i (unit)

U_j capacity of distribution center j (m^3)

γ_k unit volume of item type k (m^3)

B_0 pre-disaster budget ($)

B_1 post-disaster budget ($)

g_{jk} unit cost of acquiring item type k at distribution center j ($/unit)

c_{ijk} unit cost of shipping item type k from distribution center j to demand point i ($/unit)

w_k criticality weight for item type k; $\sum_k w_k = 1$ and $w_k \geq 0$

M a very large positive number

Decision variables:

f_{ijk} proportion of item type k relief demand satisfied by distribution center j that provide services in disaster area i

Q_{jk} units of item type k stored at distribution center j

a_{ij} set of potential response time of distribution center j that will provide service in disaster area i (a_{ij}= 1; if expected time T is no bigger than maximum response time limit, 0 otherwise)

X_{ij} set of potential distribution center j to provide service in disaster area i (X_{ij}= 1, if distribution center j provides service in disaster area i, 0 otherwise)

Then, the single-stage model is formulated as follows:

$$Max = \sum_{i\epsilon I}\sum_{k\epsilon K}\sum_{j\epsilon J^i} p_i d_{ik} w_k f_{ijk} \quad (1)$$

$$\sum_{k\epsilon K} f_{ijk} \leq M X_{ij}, \qquad \forall i\epsilon I, j\epsilon J, \quad (2)$$

$$\sum_{j\epsilon J} f_{ijk} \leq 1, \qquad \forall i\epsilon I, k\epsilon K, \quad (3)$$

$$f_{ijk} d_{ik} \leq Q_{jk}\,, \qquad \forall i\epsilon I, j\epsilon J, k\epsilon K, \quad (4)$$

$$\sum_{k\epsilon K} \gamma_k Q_{jk} \leq U_j\,, \qquad \forall j\epsilon J, \tag{5}$$

$$\sum_{j\in J} \sum_{k\epsilon K} Q_{jk} g_{jk} \leq B_o, \tag{6}$$

$$\sum_{k\epsilon K} \sum_{j\epsilon J} d_{ik} c_{ijk} f_{ijk} \leq B_1, \quad \forall i\epsilon I, \tag{7}$$

$$f_{ijk} \geq 0, \qquad \forall i\epsilon I, j\epsilon J, k\epsilon K, \tag{8}$$

$$a_{ij} T_{ij} \leq \delta_i, \qquad \forall i\epsilon I, j\epsilon J, \tag{9}$$

$$a_{ij} \geq X_{ij}, \qquad \forall i\epsilon I, j\epsilon J, \tag{10}$$

$$\sum_{j\in J} X_{ij} \geq 1, \qquad \forall i\,\epsilon I, i \neq j, \tag{11}$$

$$a_{ij} \in (0,1), \qquad \forall i\epsilon I, j\epsilon J, \tag{12}$$

$$X_{ij} \in (0,1), \qquad \forall i\epsilon I, j\epsilon J, \tag{13}$$

The objective function (1) maximizes the total expected relief demand covered by the existing distribution centers. Constraint set (2) ensures the amount of supplies sent to satisfy relief demand that only exists when the distribution center provides service in designated disaster areas. Constraint set (3) means the amount of supplies sent to satisfy relief demand in specific disaster area that does not exceed the actual demand. Constrain set (4) requires the inventory level at a single distribution center that is no smaller than the maximum amount of demand. Constraint set (5) guarantees that the amount of inventory kept at any distribution center does not exceed its capacity. Constraint set (6) requires that the preparedness expenditures related to provision of logistics for basic needs in emergency does not exceed the pre-disaster budget. Constraint set (7) means that the transportation costs to mobilize resources are less than the expected post-disaster budget. Constraint set (8) describes the non-negativity constraint on the proportion of demand satisfied. Constraint set (9) guarantees that the existing distribution center can only provide service in specific disaster area if the expected time to satisfy relief demand is no bigger than the maximum response

time limit. Constraint set (10) guarantees that a distribution center will not provide service in specific disaster area if the expected time to satisfy relief demand is bigger than the maximum response time limit. Constraint set (11) assures that at least one distribution center will provide service in any disaster area. Constraint set (12) and (13) define the binary variable of potential response time and service area for each distribution center, respectively.

In this case, we make an adjustment to the model formulation to be used in the real system. Thus, the constraint set (11) is changed to:

$$\sum_{j \in J} X_{ij} \geq 2, \qquad \forall i \in I_1, \qquad (11.a)$$

$$\sum_{j \in J} X_{ij} \geq 1, \qquad \forall i \in I_0, \qquad (11.b)$$

Following the situation in Indonesia, constraint set (11.a) assures that at least two distribution centers will provide services in disaster area that already has one existing distribution center (I_1). This is intended to cover the possibility of losing a distribution center *j* that located in disaster area *i*. Constraint set (11.b) assures that at least one distribution center will provide service in disaster area with zero existing distribution center (I_0).

3.2 Data Construction

3.2.1 System to be modeled: Indonesia

Indonesia is one of developing country located in South-East Asia region with more than 230 million of total population in early 2011, which made it the world's fourth most populous country. Indonesia is considered as an earthquake-prone country because it is situated at the meeting points of three active plates, i.e. the Indo Australian plate to the south, the Euro Asian plate to the north and the

Pacific plate in the east. The tree plates are moving and thrusting into each other in such a way that the Indo Australian plate thrusts under the Euro Asian plate which could potentially cause earthquake when the plates collide. The areas filled with dark color in Figure 11 represent the earthquake prone areas in Indonesia.

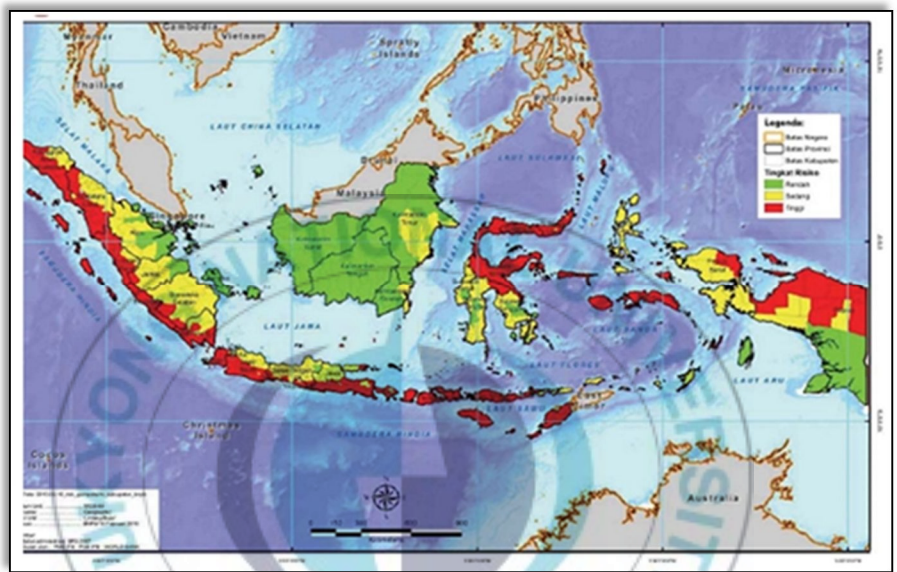


Figure 11. Earthquake risk index map in Indonesia [14]

The deadliest disaster occurred in early 21st century. On 26 December 2004, a big earthquake struck in the sea near Simeuleu island, west of Sumatra island. The earthquake triggered a tsunami that later killed more than 225,000 people in eleven countries and devastated coastal areas in the countries it affected. During the 20th century there were only few disasters with massive victims like the 2004 tsunami. In Indonesia alone the earthquake and tsunami killed around 165,708 people and affected a loss of over Rp. 48 trillion (more than $5,500,000,000) [14]. According to the official website of Meteorology, Climatology and Geophysics Agency of Indonesia (http://www.bmkg.go.id), in 2010, Indonesia was hit by 289

events of earthquake, range from magnitude 1.0 to 9.5 Mw. Table 3 shows several earthquake events in Indonesia (1896 – 2006).

Table 3. Substantial casualties in several earthquake events in Indonesia reported by the center for volcanology and mitigation of geological hazards/PVMBG,2008

No	Year	Magnitude (Mw)	Killed (persons)	Region
1	1896	-	250	Timor Island
2	1926	7.8	354	West Sumatra
3	1943	-	213	Yogyakarta and Central Java
4	1994	7	1,207	Liwa, Lampung
5	2000	7.9	100	Bengkulu
6	2005	8.7	> 1,000	Nias Islands
7	2006	6.2	> 5,700	Yogyakarta and Central Java

Due to face the disaster complexity in the future, Indonesian governments realized that an integrated, coordinated, and comprehensive disaster management plan is needed. It is critical to improve disaster preparedness by focusing on provision of materials for emergency and temporary settlements. This policy leads to the research on stock pre-positioning.

3.2.2 Data estimation

Indonesia has 33 provinces, which in this study was considered as 33 disaster areas. According to the official website of National Agency for Disaster Management of Indonesia (http://www.bnpb.go.id), in October 2010, the Indonesian governments had distributed a number of logistics and equipments in 16 disaster-prone areas in order to support disaster preparedness. For the simplicity, this model used the 16 temporary existing distribution centers. Figure 12 and 13 show the map of 33 disaster areas and location of 16 temporary existing distribution centers, respectively. The detail of the figures is described in table 4.

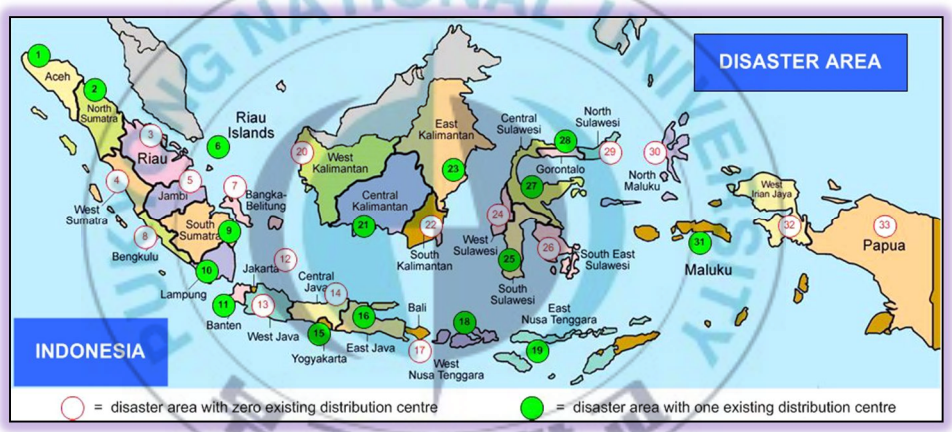


Figure 12. Map of 33 disaster areas

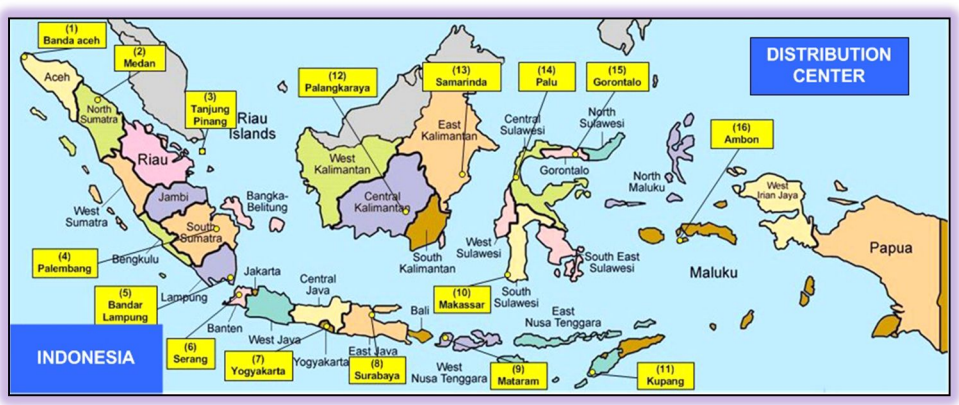


Figure 13. Location of 16 distribution centers

Table 4. Data set

Number of disaster area: 33	**Number of distribution center: 16**	**Number of item type: 9**
1. Aceh* 2. North Sumatra* 3. Riau* 4. West Sumatra 5. Jambi 6. Riau Island 7. Bangka-Belitung 8. Bengkulu 9. South Sumatra* 10. Lampung* 11. Banten* 12. Jakarta 13. West Java 14. Central Java 15. Yogyakarta* 16. East Java* 17. Bali 18. West Nusa Tenggara* 19. East Nusa Tenggara* 20. West Kalimantan 21. Central Kalimantan* 22. South Kalimantan 23. East Kalimantan* 24. West Sulawesi 25. South Sulawesi* 26. South East Sulawesi 27. Central Sulawesi* 28. Gorontalo* 29. North Sulawesi 30. North Maluku 31. Maluku* 32. West Papua 33. Papua	1. Banda Aceh 2. Medan 3. Tanjung Pinang 4. Palembang 5. Bandar Lampung 6. Serang 7. Yogyakarta 8. Surabaya 9. Mataram 10. Makassar 11. Kupang 12. Palangkaraya 13. Samarinda 14. Palu 15. Gorontalo 16. Ambon	A. Medicine (box) B. Instant food (box) C. Rice (per Kg sack) D. Drinking water (box) E. Blanket (unit) F. Clothes (packet) G. Tent (unit) H. Mat (unit) I. Lantern lamp (unit)

* Disaster area with one existing distribution center

The data set consists of 33 disaster areas and 16 distribution centers. The location of 16 distribution centers is scattered in 16 different disaster areas. Because the number of distribution center is smaller than the number of disaster

area, in this case, a distribution center serves one or more disaster areas and one disaster area possibly served by one or more distribution centers.

Commonly, disaster relief consists of many items, including consumable and inconsumable items. The items needed are very diverse and difficult to be accurately satisfied. Since there were too many item types needed for disaster relief, in this study, the items were limited up to nine critical item types.

Expected response time is calculated by dividing the distance from distribution center to the affected area with the vehicle speed. The result will be added to the expected loading time. There are so many possibility of vehicle used to ship each items into demand points. In this study, Helicopters are used to transport each item to the affected area. By considering the geographical condition in Indonesia, which consists of many islands and mountains, helicopter is the most likely vehicle used to perform an emergency response. The expected loading time is set to be 2 hours (the same for each item).

The distance from a distribution center to an affected area is easily obtained by using the application of distance measurement tools provided by Google maps. Figure 14 shows the example of distance calculation from the distribution center 7 (Yogyakarta) to the disaster area 17 (Bali) provided by Google maps.

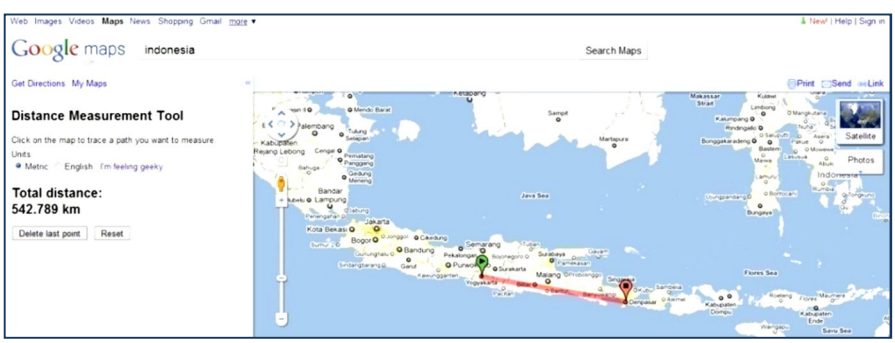


Figure 14. Distance measurement provided by Google maps (http://maps.google.com)

Maximum response time limit is flexible. It depends on governments policy, distance between distribution center and demand point, budget limitation, vehicle used, and other factors that need to be considered. In order to perform a quick response time, the maximum response time limit is set to be 8 hours (with a consideration that all disaster areas can be reached by distribution centers).

The probability of earthquake for each disaster area is estimated by Irsyam *et. al.* [12] using the principal of 6 earthquake zones of Indonesia (Figure 15). The 33 disaster areas grouped into 6 earthquake zones. As the result, the frequency of occurrence of earthquake in each disaster area is estimated [Appendix C].

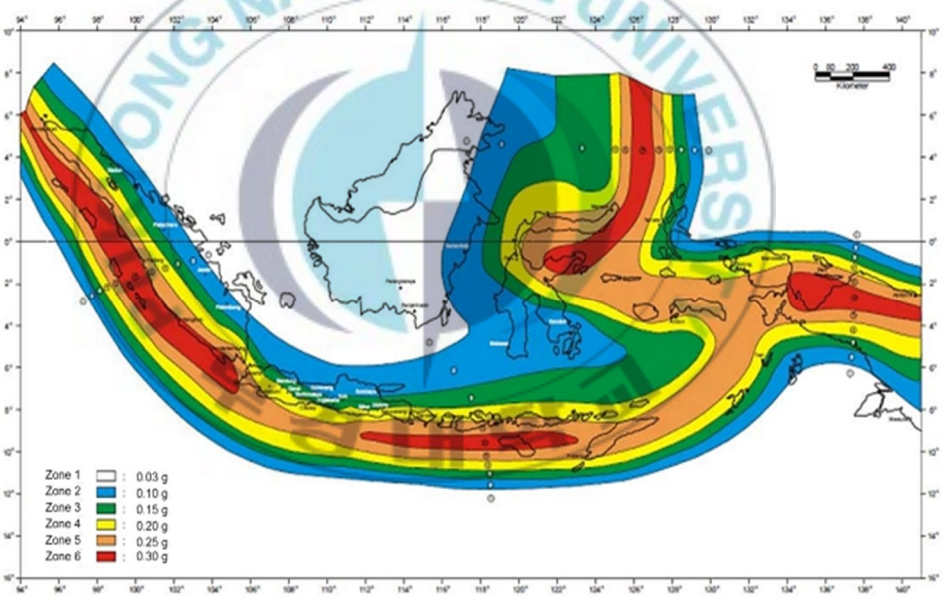


Figure 15. Indonesia earthquake map (Summary of study results of Indonesia earthquake map's revision team, 2010, pp.5)

Amount of relief demand would be very difficult or if not, nearly impossible to predict since there is no guarantee of how large the area that would be affected by the present of earthquake or how big the magnitude of earthquake

would strike a single disaster area. Therefore, Indonesia population in year 2010 is used for the demand estimation. The rest of the data to be used in the model formulation is estimated in Table 5.

Criticality weights are obtained by classifying all items into two groups: primary and secondary items. Primary items get the bigger priority comparing to secondary items. Primary items are medicine, instant food, rice, drinking water, clothes, and tent. Secondary items are blanket, mat, and lantern lamp. Score of 1 or expected to be met as big as 100% is given to primary items, while score of 0.5 or expected to be met as big as 50% is given to secondary items. The total of criticality weight must equal to 1.

Volume of each item type is clearly mentioned in Table 5. The capacity of each distribution center is obtained by assuming that all distribution centers have the same size. The distribution center area is 1 hectare or 10,000 m^2. The dimension of each distribution center is 100x100x12 = 120,000 m^3. Normally, only 70% space is used for the storage. Hence, the capacity of each distribution center is 84,000 m^3.

Unit cost of acquiring relief item is estimated from the purchase price of each item, where 1 US dollar is assumed to be equal to 8,650 Rupiah. To calculate the unit cost of shipping, it is necessary to assume the maximum load of helicopter. The maximum load of medium size of helicopter can be assumed to be 6.23 m^3 for one way trip. To calculate the shipping cost per unit item type, first, calculate the unit cost of shipping formulated in Table 5 to obtain the shipping cost for one way trip. Next, the result of calculation of shipping cost for one way trip is should be divided by the capacity of each item type.

Maximum pre-disaster and post-disaster budget were adapted from the budget allocation of Indonesian governments in period 2010-2014 [14]. The rest of data estimations are seen in appendix A and B.

Table 5. Data estimation

Expected response time	(distance from distribution center to the affected area (Km)) / vehicle speed (Km/hr)) + (expected loading time (hr))
Maximum response time	Expected to be 8 hours since the earthquake (the same for each disaster area)
Probability of earthquake	Calculated based on the frequency of earthquake hit each disaster area during the last 6 years (2005-2010). The earthquake magnitude varies between 1.0 to 9.0 Mw.
Amount of demand	Estimated from the total population of each province in 2010.
Criticality weight	Weight of each item type / total weight (Weight of each item type respectively = 0.13, 0.13, 0.13, 0.13, 0.07, 0.13, 0.13, 0.07, 0.07)
Volume	Unit volume of each item type respectively = 0.01887 m^3; 0.054 m^3; 0.02 m^3; 0.054 m^3; 0.009 m^3; 0.1119 m^3; 0.2 m^3; 0.05625 m^3; 0.005625 m^3
Distribution center capacity	84,000 m^3 (the same for each distribution center)
Unit cost of acquring relief items	Unit cost of each item type respectively = \$364.162; \$5.78; \$0.925; \$3.699; \$6.936; \$11.561; \$751.445; \$8.671; \$8.092. (1 USD = Rp. 8,650)
Unit cost of shipping from distribution center to the affected area	(Expected response time (hr)) x (Kerosene needed (litre/hour)) x 2 (round trip)
Maximum pre-disaster budget available	\$857,317,919.075
Maximum post-disaster budget available	\$116,589,595.375

Chapter 4. Computational Results

4.1 Results of the single-stage model formulation

This section analyzes the results of each decision variable including service area of each distribution center, the maximum unit of item types stocked in each distribution centre, and the proportion of relief demand satisfied. LINGO 8.0 was used for finding the optimal solutions with the mathematical model presented in Chapter 3. All experiments solving each problem are tested on a personal computer with an Intel(R) Core(TM)2 Duo CPU 2.93GHz and 2.00 GB of RAM. The computation time of all the test problems was less than 1 second.

4.1.1 Service area

The basic constraints of this model are that each distribution center can serve more than one disaster area and a disaster area should be served by more than one like the general assignment problem. If the realistic situation by the national disaster management plan of Indonesia [14] is reflected to the model, the disaster area with one existing distribution center should be served by at least two distribution centers. Since the maximum response time is set by 8 hours, a distribution center located within more than 8 hours from a disaster area could not serve to the disaster area.

Table 6a and 6b show the results of service area of each distribution center solved by Lingo. The summary of Table 6a and 6b is provided in Table 7. There were 33 disaster areas that must be covered by 16 distribution centers. Disaster area 23 (East Kalimantan) that located in the middle of Indonesia received the most services from 14 distribution centers. The next disaster areas that received a

large number of services were disaster area 7 (Bangka Belitung), 16 (East Java), 20 (West Kalimantan), 21 (Central Kalimantan), and 22 (South Kalimantan). All of the five disaster areas could be served by 13 distribution centers. In contrast, disaster area 33 (Papua), received the smallest number of services from only one distribution center (distribution center 16, Ambon).

Table 6a. Service area of distribution center 1 to 8
(maximum response time = 8 hours)

DISASTER AREA		RESP. TIME (hours)	DISTRIBUTION CENTRE							
			1	2	3	4	5	6	7	8
			Banda Aceh	Medan	Tanjung Pinang	Palembang	Bandar Lampung	Serang	Yogya	Surabaya
1	Aceh**	8	*	*	*	*				
2	North Sumatra**	8	*	*	*	*	*	*		
3	Riau	8	*	*	*	*	*	*	*	*
4	West Sumatra	8	*	*	*	*	*	*	*	*
5	Jambi	8	*	*	*	*	*	*	*	*
6	Riau Island**	8	*	*	*	*	*	*	*	*
7	Bangka Belitung	8	*	*	*	*	*	*	*	*
8	Bengkulu	8	*	*	*	*	*	*	*	*
9	South Sumatra**	8	*	*	*	*	*	*	*	*
10	Lampung**	8		*	*	*	*	*	*	*
11	Banten**	8		*	*	*	*	*	*	*
12	Jakarta	8		*	*	*	*	*	*	*
13	West Java	8		*	*	*	*	*	*	*
14	Central Java	8			*	*	*	*	*	*
15	Yogyakarta**	8			*	*	*	*	*	*
16	East Java**	8			*	*	*	*	*	*
17	Bali	8				*	*	*	*	*
18	West Nusa Tenggara**	8				*	*	*	*	*
19	East Nusa Tenggara**	8							*	*
20	West Kalimantan	8		*	*	*	*	*	*	*

21	Central Kalimantan**	8			*	*	*	*	*	*
22	South Kalimantan	8			*	*	*	*	*	*
23	East Kalimantan**	8			*	*	*	*	*	*
24	West Sulawesi	8					*	*	*	*
25	South Sulawesi**	8						*	*	*
26	South East Sulawesi	8							*	*
27	Central Sulawesi**	8							*	*
28	Gorontalo**	8								
29	North Sulawesi	8								*
30	North Maluku	8								
31	Maluku**	8								
32	West Papua	8								
33	Papua	8								

*) Distribution center *j* provides service for disaster area *i*

**) Disaster area with one existing distribution center

Table 6b. Service area of distribution center 9-16
(maximum response time = 8 hours)

DISASTER AREA		RESP. TIME (hours)	DISTRIBUTION CENTER							
			9	10	11	12	13	14	15	16
			Mataram	Mkssar	Kupang	Palang-karaya	Samarin-da	Palu	Goron-talo	Ambon
1	Aceh**	8								
2	North Sumatra**	8								
3	Riau	8				*				
4	West Sumatra	8				*				
5	Jambi	8				*	*			
6	Riau Island**	8				*	*			
7	Bangka Belitung	8	*	*		*	*	*		

8	**Bengkulu**	**8**				*				
9	**South Sumatra****	**8**	*			*	*			
10	**Lampung****	**8**	*			*	*			
11	**Banten****	**8**	*	*		*	*			
12	**Jakarta**	**8**	*	*		*	*	*		
13	**West Java**	**8**	*	*		*	*	*		
14	**Central Java**	**8**	*	*	*	*	*	*		
15	**Yogyakarta****	**8**	*	*	*	*	*	*		
16	**East Java****	**8**	*	*	*	*	*	*	*	
17	**Bali**	**8**	*	*	*	*	*	*	*	
18	**West Nusa Tenggara****	**8**	*	*	*	*	*	*	*	*
19	**East Nusa Tenggara****	**8**	*	*	*	*	*	*	*	*
20	**West Kalimantan**	**8**	*	*		*	*	*	*	
21	**Central Kalimantan****	**8**	*	*	*	*	*	*	*	
22	**South Kalimantan**	**8**	*	*	*	*	*	*	*	
23	**East Kalimantan****	**8**	*	*	*	*	*	*	*	*
24	**West Sulawesi**	**8**	*	*	*	*	*	*	*	*
25	**South Sulawesi****	**8**	*	*	*	*	*	*	*	*
26	**South East Sulawesi**	**8**	*	*	*	*	*	*	*	*
27	**Central Sulawesi****	**8**	*	*	*	*	*	*	*	*
28	**Gorontalo****	**8**	*	*	*	*	*	*	*	*
29	**North Sulawesi**	**8**	*	*	*	*	*	*	*	*
30	**North Maluku**	**8**		*	*	*	*	*	*	*
31	**Maluku****	**8**	*	*	*		*	*	*	*
32	**West Papua**	**8**							*	*
33	**Papua**	**8**								*

* Distribution center *j* provides service for disaster area *i*

** Disaster area with one existing distribution center

Figure 16 summarizes the number of distribution centers that serves each disaster area. Refering to the explanation in section 4.1.1, disaster areas with zero existing distribution center must be served by at least one distribution center, while disaster areas with one existing distribution center must be served by at least two distribution centers. Based on Figure 16, the model is valid since all disaster areas with zero existing distribution center have been served by at least one distribution center, and all disaster areas with one existing distribution center have been served by at least two distribution centers.

Disaster area 1 (Aceh) that located in the western part of Indonesia along with disaster area 32 (West Papua) and 33 (Papua) that located in the eastern part of Indonesia received the smallest services. Meanwhile, disaster area 7 (Bangka Belitung) and 23 (East Kalimantan) that located in the middle of Indonesia, received the largest services. This is due to the location of disaster area 1, 32, and 33 far from the most location of distribution centers.

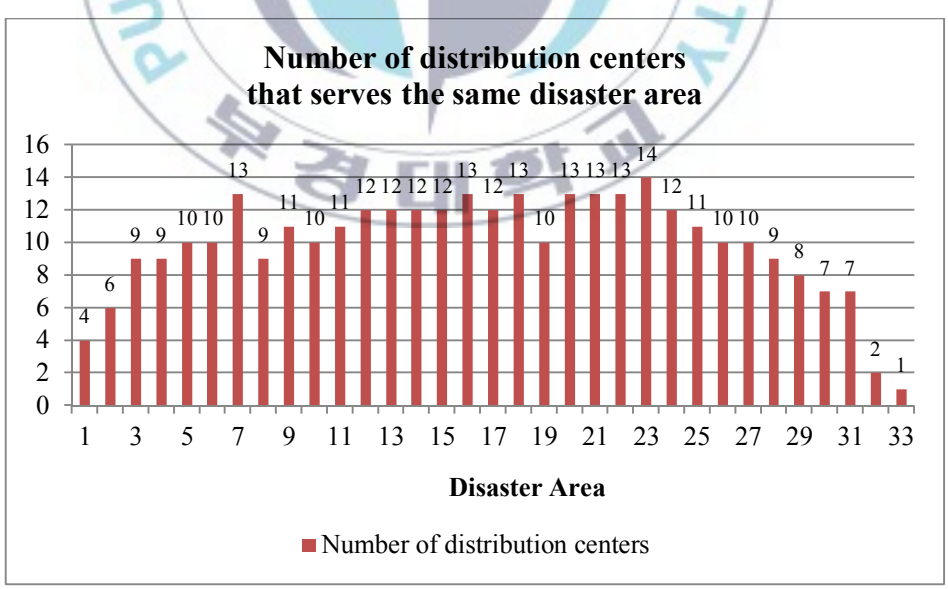


Figure 16. Number of distribution centers that serves the same disaster area

Figure 17 shows the result of the total disaster areas served by a single distribution center with maximum 8 hours of response time. If disaster area 23 (East Kalimantan) received the most services, distribution center 12 (Palangkaraya) that also located in Kalimantan island, could be able to serve up to 28 disaster areas. That is the largest number for a single distribution to cover the expected relief demand of disaster areas. The capability of distribution center 12 to serve a large number of disaster areas is due to its strategic location, compared to the other distribution centers. Distribution center 8 (Surabaya) and 13 (Samarinda) covered 26 disaster areas. In contrast, distribution center 1 (Banda Aceh) that located in western part of Indonesia could only serve 9 disaster areas. This is due to the location of distribution center 1 far from the most location of disaster areas. These results greatly affect the optimum amount of inventory to be stocked in each distribution center.

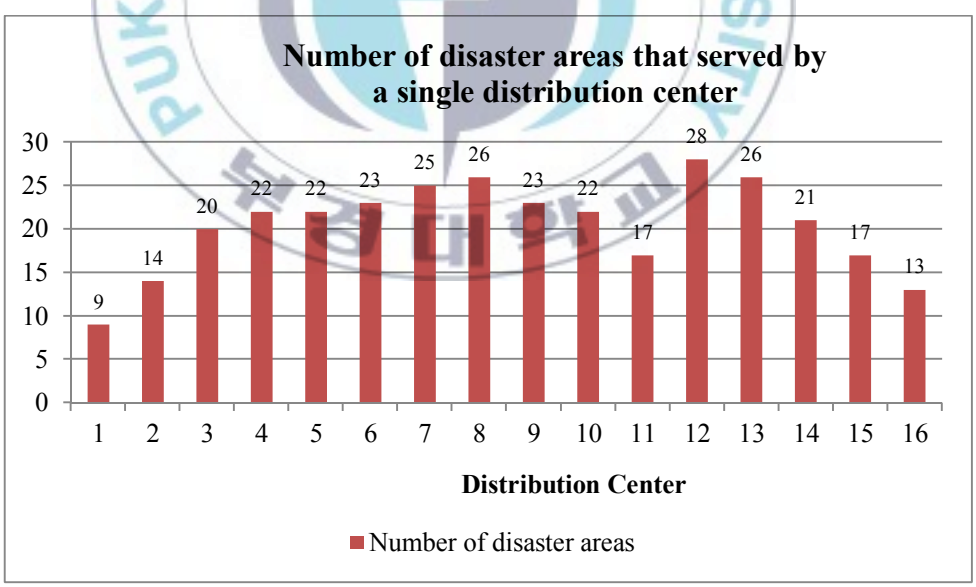


Figure 17. The number of disaster areas that served by a single distribution center

4.1.2 Total inventory

The optimum result for the total items stocked in each distribution center under 8 hours of maximum response time, $857,317,919.08 of pre-disaster budget, $116,589,595.38 of post-disaster budget, and 84,000 m^3 of distribution center capacity is shown in Table 7a and 7b.

Table 7a. Total inventory of each distribution center for item type A, B, C, and D

Distribution Centre		Total Inventory (unit)			
		Medicine (A)	Instant food (B)	Rice (C)	Drinking water (D)
1	Banda Aceh	0.00	0.00	3,919,487.00	103,893.70
2	Medan	0.00	584,916.00	0.00	970,639.60
3	Tanjung Pinang	0.00	0.00	2,852,478.00	0.00
4	Palembang	0.00	0.00	2,072,178.00	0.00
5	Bandar Lampung	0.00	0.00	4,094,526.00	0.00
6	Serang	0.00	0.00	2,692,073.00	0.00
7	Yogyakarta	0.00	176,433.00	0.00	541,102.70
8	Surabaya	0.00	208,033.00	0.00	0.00
9	Mataram	0.00	344,682.00	1,312,854.00	678,363.70
10	Makassar	0.00	0.00	0.00	4,200,000.00
11	Kupang	0.00	0.00	0.00	0.00
12	Palangkaraya	1,761,262.00	0.00	0.00	0.00
13	Samarinda	0.00	207,617.00	0.00	346,029.00
14	Palu	0.00	0.00	2,912,601.00	0.00
15	Gorontalo	0.00	0.00	0.00	0.00
16	Ambon	0.00	0.00	2,858,571.00	0.00

Table 7b. Total inventory of each distribution center for item type E, F, G, H, and I

Distribution Centre		Total Inventory (unit)				
		Blanket (E)	Clothes (F)	Tent (G)	Mat (H)	Lantern Lamp (I)
1	Banda Aceh	0.00	0.00	0.00	0.00	0.00
2	Medan	0.00	0.00	0.00	0.00	0.00
3	Tjg Pinang	2,786,807.00	0.00	0.00	0.00	332,298.00
4	Palembang	4,494,410.00	0.00	0.00	0.00	374,534.00
5	Bandar Lmpg	0.00	0.00	0.00	0.00	375,018.00
6	Serang	3,350,949.00	0.00	0.00	0.00	0.00
7	Yogyakarta	0.00	268,668.90	0.00	270,027.00	0.00
8	Surabaya	0.00	650,279.00	0.00	0.00	0.00
9	Mataram	0.00	0.00	0.00	44,416.91	0.00
10	Makassar	0.00	0.00	0.00	0.00	0.00
11	Kupang	0.00	750,670.20	0.00	0.00	0.00
12	Palangkaraya	0.00	445,674.70	0.00	15,893.00	0.00
13	Samarinda	0.00	368,151.10	0.00	229,458.00	0.00
14	Palu	1,850,446.00	0.00	0.00	0.00	1,616,705.00
15	Gorontalo	0.00	706,100.00	0.00	88,665.09	0.00
16	Ambon	2,833,381.00	0.00	0.00	0.00	236,115.00

The result showed that the maximum expected relief demand covered in 33 disaster areas is 17,979,240 units. Figure 18 shows the total amount of 22,714,768 units of item type C that was stocked in 8 distribution centers. Also, item type C had the largest amount stocked in distribution centers.

Compared to item type C that has the largest amount stocked in distribution centers, item type G (tent) has zero value. Meaning, there is no item type G stocked in all distribution centers. This is due to its higher price and larger volume compared to another item.

Item type A (medicine) which considered as a very important item in disaster reliefs was only stocked in one distribution center, distribution center 12 (Palangkaraya). Despite item A only stocked in one distribution center, the amount of item A reached 1,761,262 units which was big enough to cover the relief demand of certain disaster areas.

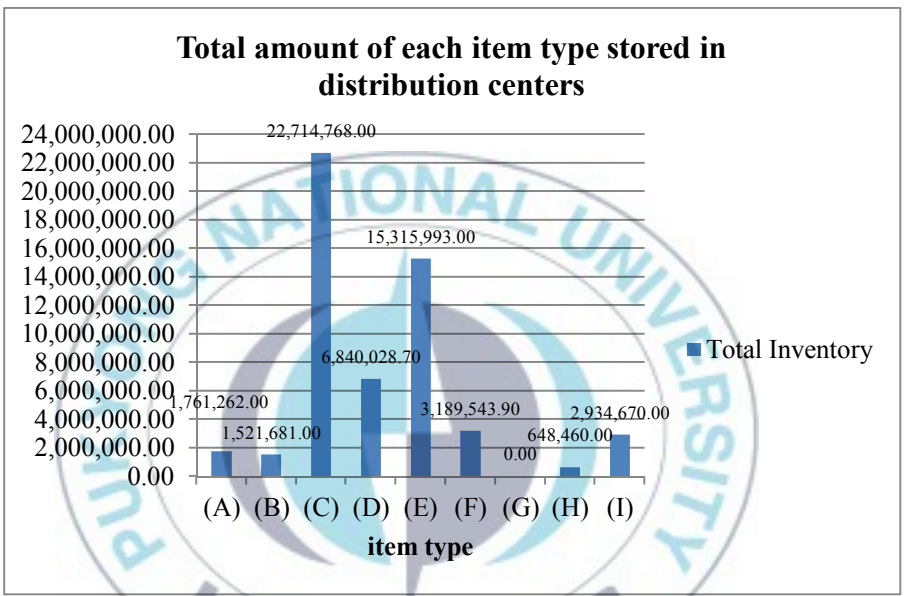


Figure 18. Total amount of item type stocked in distribution centers

Figure 19 represents the total inventory of all item types stocked in each distribution center. Distribution center 4 (Palembang) had the largest amount of inventory (6,566,588 units). This is due to the big amount of item type C (rice) and E (blanket) stocked in this distribution center. In contrast, distribution center 11 (Kupang) had the smallest amount of inventory (750,670.20 units). The detailed results are seen in appendix F.

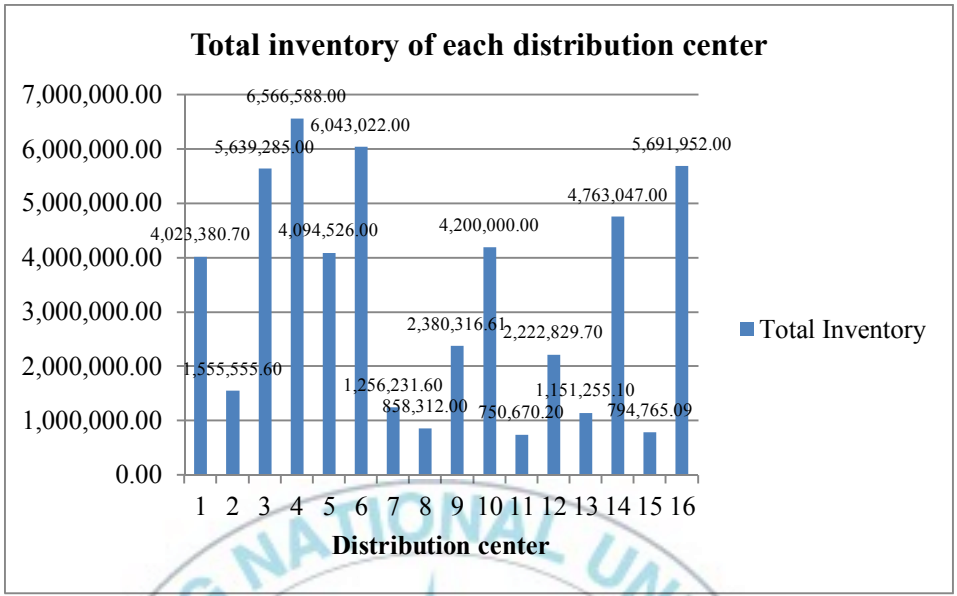


Figure 19. Total inventory of all item types stocked in each distribution center

4.1.3 Proportion of relief demand satisfied

The proportion of relief demand satisfied is one of the most important issues in this study. Under the condition of 8 hours of maximum response time, $857,317,919.08 of pre-disaster budget, $116,589,595.38 of post-disaster budget, and 84,000 m³ of capacity, Table 8a and 8b show the result of total proportion of relief demand satisfied in each disaster area.

Table 8a. The proportion of expected relief demand satisfied in each disaster area for item type A, B, C, D, and E

Proportion of expected relief demand in each disaster area						
Disaster area		Item type				
		Medicine	Instant food	Rice	Drinking water	Blanket
		(A)	(B)	(C)	(D)	(E)
1	Aceh	0.00	0.65	1.00	0.72	1.00
2	North Sumatra	0.00	0.23	0.74	0.25	0.82

3	**Riau**	0.32	0.88	1.00	0.88	1.00
4	**West Sumatra**	0.36	1.00	1.00	1.00	1.00
5	**Jambi**	0.57	1.00	1.00	1.00	1.00
6	**Riau Island**	1.00	1.00	1.00	1.00	1.00
7	**Bangka Belitung**	1.00	1.00	1.00	1.00	1.00
8	**Bengkulu**	1.00	1.00	1.00	1.00	1.00
9	**South Sumatra**	0.24	1.00	1.00	1.00	1.00
10	**Lampung**	0.23	1.00	1.00	1.00	1.00
11	**Banten**	0.17	0.72	1.00	0.72	1.00
12	**Jakarta**	0.18	0.79	1.00	0.79	1.00
13	**West Java**	0.04	0.18	0.29	0.18	0.29
14	**Central Java**	0.05	0.14	0.38	0.15	0.39
15	**Yogyakarta**	0.51	1.00	1.00	1.00	1.00
16	**East Java**	0.05	0.12	0.33	0.13	0.33
17	**Bali**	0.45	1.00	1.00	1.00	1.00
18	**West Nusa Tenggara**	0.39	1.00	1.00	1.00	1.00
19	**East Nusa Tenggara**	0.38	1.00	1.00	1.00	1.00
20	**West Kalimantan**	0.40	1.00	1.00	1.00	1.00
21	**Central Kalimantan**	0.80	1.00	1.00	1.00	1.00
22	**South Kalimantan**	0.49	1.00	1.00	1.00	1.00
23	**East Kalimantan**	0.50	1.00	1.00	1.00	1.00
24	**West Sulawesi**	1.00	1.00	1.00	1.00	1.00
25	**South Sulawesi**	0.22	0.58	1.00	0.58	1.00
26	**South East Sulawesi**	0.79	1.00	1.00	1.00	1.00
27	**Central Sulawesi**	0.67	1.00	1.00	1.00	1.00
28	**Gorontalo**	1.00	1.00	1.00	1.00	1.00
29	**North Sulawesi**	0.78	1.00	1.00	1.00	1.00
30	**North Maluku**	1.00	1.00	1.00	1.00	1.00
31	**Maluku**	0.00	1.00	1.00	1.00	1.00
32	**West Papua**	0.00	0.00	1.00	0.00	1.00
33	**Papua**	0.00	0.00	0.62	0.00	1.00

Table 8b. The proportion of expected relief demand satisfied in each disaster area for item type F, G, H, and I

Proportion of expected relief demand in each disaster area					
Disaster area		Item type			
		Clothes (F)	Tent (G)	Mat (H)	Lantern Lamp (I)
1	Aceh	0.00	0.00	0.00	1.00
2	North Sumatra	0.00	0.00	0.00	1.00
3	Riau	0.25	0.00	0.31	1.00
4	West Sumatra	0.28	0.00	0.35	1.00
5	Jambi	0.56	0.00	1.00	1.00
6	Riau Island	1.00	0.00	1.00	1.00
7	Bangka Belitung	1.00	0.00	1.00	1.00
8	Bengkulu	0.80	0.00	1.00	1.00
9	South Sumatra	0.23	0.00	0.45	1.00
10	Lampung	0.23	0.00	0.44	1.00
11	Banten	0.16	0.00	0.32	1.00
12	Jakarta	0.18	0.00	0.35	1.00
13	West Java	0.04	0.00	0.08	0.75
14	Central Java	0.08	0.00	0.10	1.00
15	Yogyakarta	0.72	0.00	0.97	1.00
16	East Java	0.09	0.00	0.10	0.86
17	Bali	0.82	0.00	1.00	1.00
18	West Nusa Tenggara	0.71	0.00	0.86	1.00
19	East Nusa Tenggara	0.68	0.00	0.83	1.00
20	West Kalimantan	0.55	0.00	0.89	1.00
21	Central Kalimantan	1.00	0.00	1.00	1.00
22	South Kalimantan	0.88	0.00	1.00	1.00
23	East Kalimantan	0.90	0.00	1.00	1.00
24	West Sulawesi	1.00	0.00	1.00	1.00
25	South Sulawesi	0.40	0.00	0.48	1.00
26	South East Sulawesi	1.00	0.00	1.00	1.00

27	**Central Sulawesi**	1.00	0.00	1.00	1.00
28	**Gorontalo**	1.00	0.00	1.00	1.00
29	**North Sulawesi**	1.00	0.00	1.00	1.00
30	**North Maluku**	1.00	0.00	1.00	1.00
31	**Maluku**	1.00	0.00	1.00	1.00
32	**West Papua**	0.93	0.00	0.70	1.00
33	**Papua**	0.00	0.00	0.00	1.00

The proportion of relief demand satisfied varied in 33 disaster areas. Due to the budget limitation, some of relief demands could be satisfied completely (100%) while others could not be satisfied at all (0%).

Figure 20 shows the largest proportion of relief demand satisfied of item I (lantern lamp) with the proportion of 32.62. Meanwhile the smallest proportion of relief demand satisfied would be the total proportion of item type G (tent) with zero value. This is due to its expensive price and large volume for one unit of item type G.

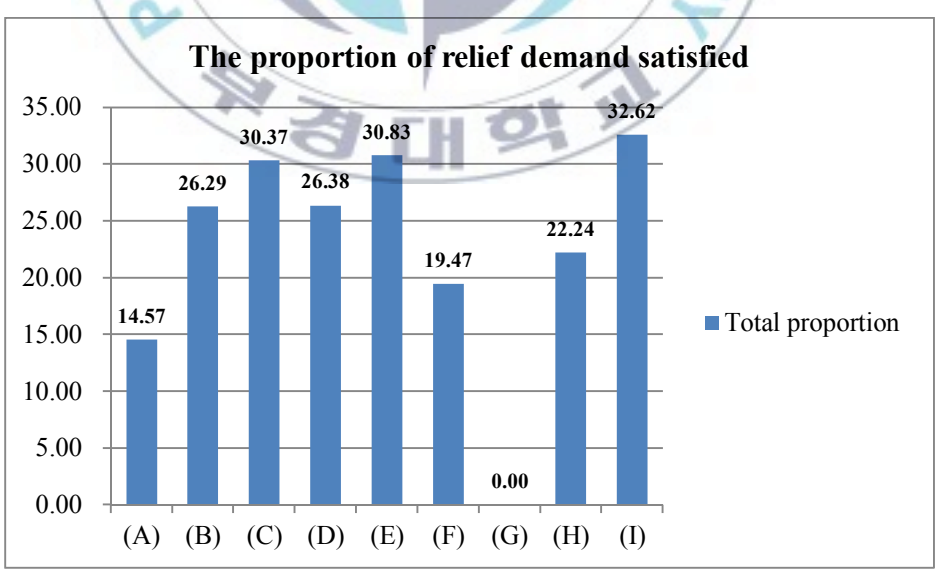


Figure 20. The proportion of relief demand satisfied

4.2 Sensitivity analysis

A sensitivity analysis is performed by changing the sensitive parameters of maximum response time, budgets, and capacity of each distribution center. We set the maximum response time to be 7.3, 8, 10, 12, 16, 20, and 22 hours. The rest of the scenarios can be seen in Table 9.

Table 9. Maximum response time, budgets, and distribution center capacity scenario for sensitivity analysis

Maximum response time (hours)	**7.3, 8, 10, 12, 16, 20, 22**	
Budgets ($)	**Pre-disaster budgets ($)**	**Post-disaster budgets ($)**
(1) Real budgets-determined by the governments (x)	**857,317,919.08**	**116,589,595.38**
(2) Increase pre-disaster budget (1.5x)	1,285,976,878.61	116,589,595.38
(3) Increase pre-disaster budget (2x)	1,714,635,838.15	116,589,595.38
(4) Increase pre-disaster budget (5x)	4,286,589,595.38	116,589,595.38
(5) Increase pre-disaster budget (10x)	8,573,179,190.75	116,589,595.38
(6) Increase post-disaster budget (1.5x)	857,317,919.08	174,884,393.06
(7) Increase post-disaster budget (2x)	857,317,919.08	233,179,190.75
(8) Increase post-disaster budget (5x)	857,317,919.08	582,947,976.88
(9) Increase post-disaster budget (10x)	857,317,919.08	1,165,895,953.75
(10) Increase all budgets (1.5x)	1,285,976,878.61	174,884,393.06
(11) Increase all budgets (2x)	1,714,635,838.15	233,179,190.75
(12) Increase all budgets (5x)	4,286,589,595.38	582,947,976.88
(13) Increase all budgets (10x)	8,573,179,190.75	1,165,895,953.75
Capacity of a single distribution center (m^3)	**84,000; 168,000**	

The budget was increased from 1.5 times to 10 times greater than its original budget. The capacity of each distribution center was increased 2 times bigger than its original capacity.

A single distribution center can only provide service into one or more disaster areas if the expected time to satisfy relief demand in affected disaster area is less than the maximum response time limit in order to perform a quick emergency response.

4.2.1 Sensitivity analysis for the number of distribution centers

Number of distribution centers that served a disaster area was varying from 1 to 16. Disaster area 33 (Papua) located in eastern part of Indonesia was covered by the minimum number of distribution centers, varying from 1 to 13. Disaster area 21 and 22 (Central Kalimantan and South Kalimantan) located in the middle of Indonesia received the largest number of services varied from 13 to the maximum of 16 distribution centers. A single disaster area must be at least served by 1 distribution center. The absence of distribution centers that provide service in certain disaster areas are not acceptable.

Number of distribution centers that covered each disaster area is shown in Table 10a, 10b, and 10c.

Table 10a. Number of distribution centers to cover a single disaster area under varying maximum response time

	Disaster Area											**Resp time (hours)**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	
	Aceh	**North Sum**	**Riau**	**West Sum**	**Jambi**	**Riau Island**	**Bangka Bel**	**Bgklu**	**South Sum**	**Lmpg**	**Banten**	
Total distribution center	3	6	7	7	9	9	10	9	9	9	10	7.3
	4	**6**	**9**	**9**	**10**	**10**	**13**	**9**	**11**	**10**	**11**	**8***
	5	9	12	11	11	14	14	13	14	14	15	10

	10	13	14	14	15	15	16	15	15	16	16	12
	15	16	16	16	16	16	16	16	16	16	16	16
	16	16	16	16	16	16	16	16	16	16	16	20
	16	16	16	16	16	16	16	16	16	16	16	22

Table 10b. Number of distribution centers to cover a single disaster area under varying maximum response time

	Disaster Area											Resp time (hours)
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	
	Jkt	**West Java**	**Central Java**	**Yogya karta**	**East Java**	**Bali**	**West Nusa Teng**	**East Nusa Teng**	**West Kal**	**Cntral Kal**	**South Kal**	
Total distribution center	9	10	11	11	12	12	11	9	12	13	13	7.3
	12	**12**	**12**	**12**	**13**	**12**	**13**	**10**	**13**	**13**	**13**	**8***
	15	15	15	15	15	14	14	11	15	15	15	10
	16	16	16	16	16	15	15	14	16	16	16	12
	16	16	16	16	16	16	16	16	16	16	16	16
	16	16	16	16	16	16	16	16	16	16	16	20
	16	16	16	16	16	16	16	16	16	16	16	22

Table 10c. Number of distribution centers to cover a single disaster area under varying maximum response time

	Disaster Area											Resp time (hours)
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	
	East Kal	**West Sul**	**South Sul**	**South East Sul**	**Central Sul**	**Goron talo**	**North Sul**	**North Mal**	**Mal**	**West Papua**	**Papua**	
Total distribution center	10	10	10	9	10	8	7	6	6	2	1	7.3
	14	**12**	**11**	**10**	**10**	**9**	**8**	**7**	**7**	**2**	**1**	**8***
	14	14	14	13	14	14	10	9	10	6	2	10
	16	15	15	14	15	14	14	14	12	9	5	12
	16	16	16	16	16	16	16	16	15	14	10	16
	16	16	16	16	16	16	16	16	16	16	14	20
	16	16	16	16	16	16	16	16	16	16	16	22

If the maximum response time was set to be 22 hours since the earthquake, all disaster areas were served by 16 distribution centers (see appendix E). Then the maximum number of distribution centers is available. If the maximum response time was set to be 7.3 hours, distribution center 33 (Papua) would be

only served by 1 distribution center. Decreasing the maximum response time (smaller than 7.3 hours) is not acceptable, since it caused a zero distribution center that provides service in certain disaster areas.

The bigger the response time, the larger the service area of each distribution center to be covered. If the maximum response time was set to be 7.3 hours, the total distribution centers were varied. If the maximum response time was set to be 22 hours, the total of distribution centers had become steady. This result is greatly affected the decision of the maximum amount of inventory kept in each distribution center.

4.2.2 Sensitivity analysis of total inventory

The sensitivity analysis of total inventory was performed based on three scenarios. Firstly, changed the budgets; secondly, changed the maximum response time; and thirdly, changed the capacity of distribution centers.

Figure 21 and 22 show the results of total expected relief demand covered by the existing distribution centers under smallest and largest maximum response time (7.3 and 22 hours). The budget was set based on budget scenario (see Table 9), while the capacity of each distribution center was set to be 84,000 m^3 (original capacity). For the detailed data, refer to appendix F.

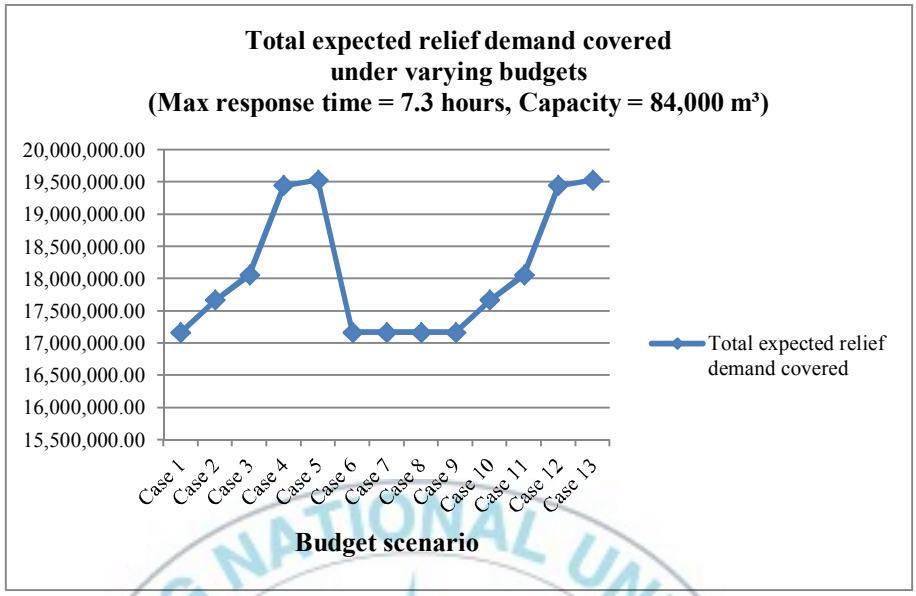


Figure 21. Total expected relief demand covered under varying budgets (maximum response time = 7.3 hours, capacity = 84,000 m³)

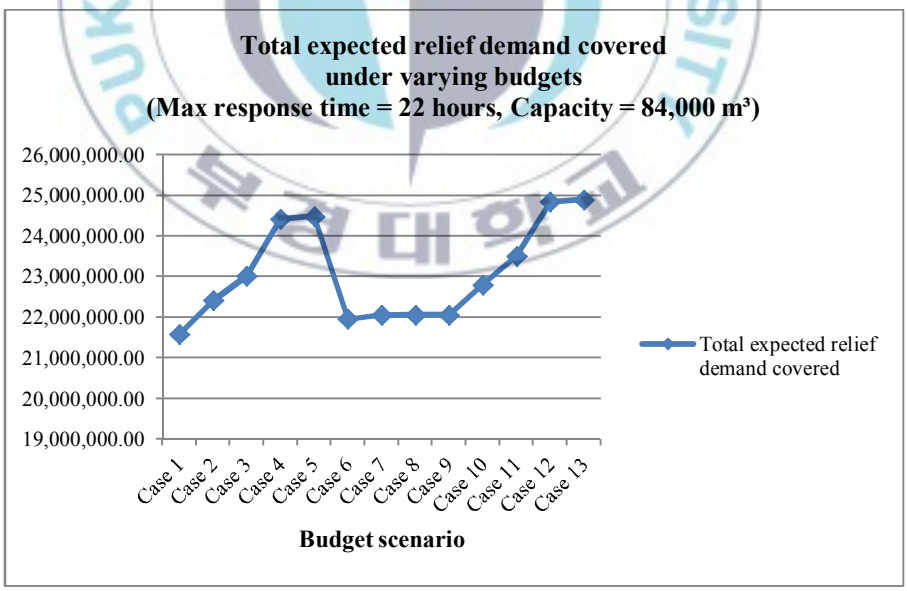


Figure 22. Total expected relief demand covered under varying budgets (maximum response time = 8 hours, capacity = 84,000 m³)

The patterns of total expected relief demand covered under varied response time were not quite different. The patterns were almost the same except for the total amount of relief demand covered. Case 1 (see Table 9) used the real pre- and post-disaster budgets determined by the governments. For the next case, one of the budgets and then both budgets were increased incrementally. It seems that increasing pre-disaster budget while keeping post-disaster budget constant can improve the total relief demand covered in large amount. On the opposite, increasing post-disaster budget while keeping pre-disaster budget constant can only slightly improve the total relief demand covered, because post-disaster budget only focus on transportation cost to mobilize resources to the affected disaster area.

The total expected relief demand covered reached its highest amount when the two budgets increased 10 times of its original budgets. Suppose the governments have unlimited budgets, the total expected relief demand will get bigger until the amount of relief demand stocked in all distribution centers reach the capacity limit and become steady. Figure 23a and 23b show the total inventory for each item type under varying budgets and capacity. The maximum response time show only for 7.3 hours and 22 hours (see appendix F for details). When the maximum response time was set to be 7.3 hours, and the distribution center capacity was set to be 84,000 m^3, item type C (rice) spent the most volume stocked in distribution centers, followed by item type F (clothes). The smallest volume stocked in distribution centers is the volume of item type G (tent) with zero value. This is due to higher price and larger size per unit of item type G. By maintaining the same maximum response time and changing the distribution center capacity to 164,000 m^3, the result of case 4, 5, 12, and 13 of budget scenario made sure that all item types were stocked, including item type G. In these cases, there were no zero item existed.

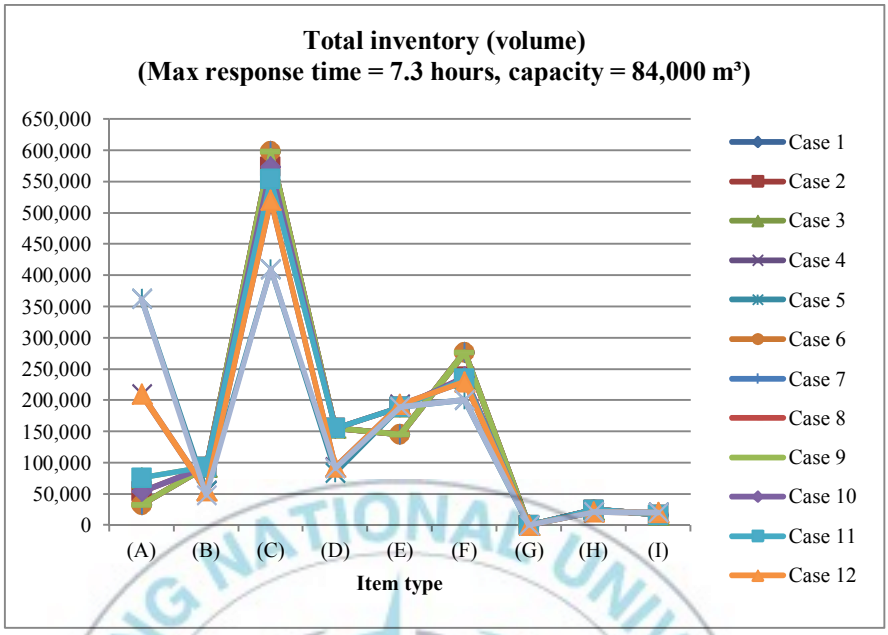


Figure 23a. Total inventory for each item type under varying budgets (maximum response time = 7.3 hours, capacity = 84,000 m³)

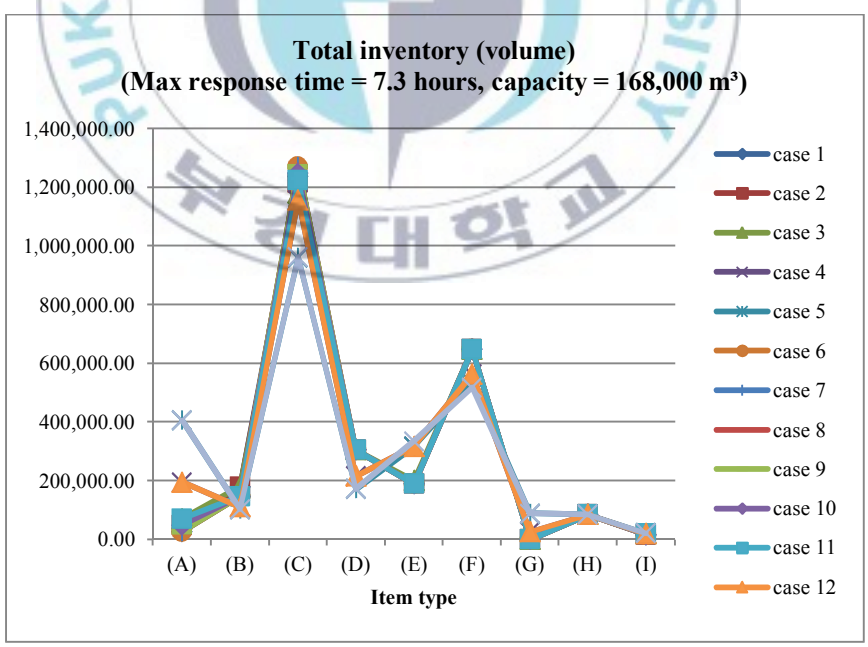


Figure 23b. Total inventory for each item type under varying budgets (maximum response time = 7.3 hours, capacity = 168,000 m³)

Another sensitivity analysis was performed by changing the maximum response time to be 22 hours. Figure 24a and 24b perform the two capacities of distribution centers (84,000 m³ and 168,000 m³) with all budget scenarios.

When the capacity of each distribution center was set to be 84,000 m³, item type F (clothes) spent the largest volume stocked in distribution centers, followed by item type C (rice). Item type G (tent) still had the smallest volume stocked in distribution centers. But the results for case 4 and 5 of budget scenario showed a small amount of item type G to be stocked in distribution centers.

The next sensitivity analysis was performed by changing the capacity of each distribution center to 168,000 m³. In this scenario, item type C (rice) had the largest volume stocked in distribution centers, followed by item type F (clothes). The results for case 4, 5, 12 and 13 of budget scenario showed a small amount of item type G to be stocked in distribution centers. For the details, refer to appendix F.

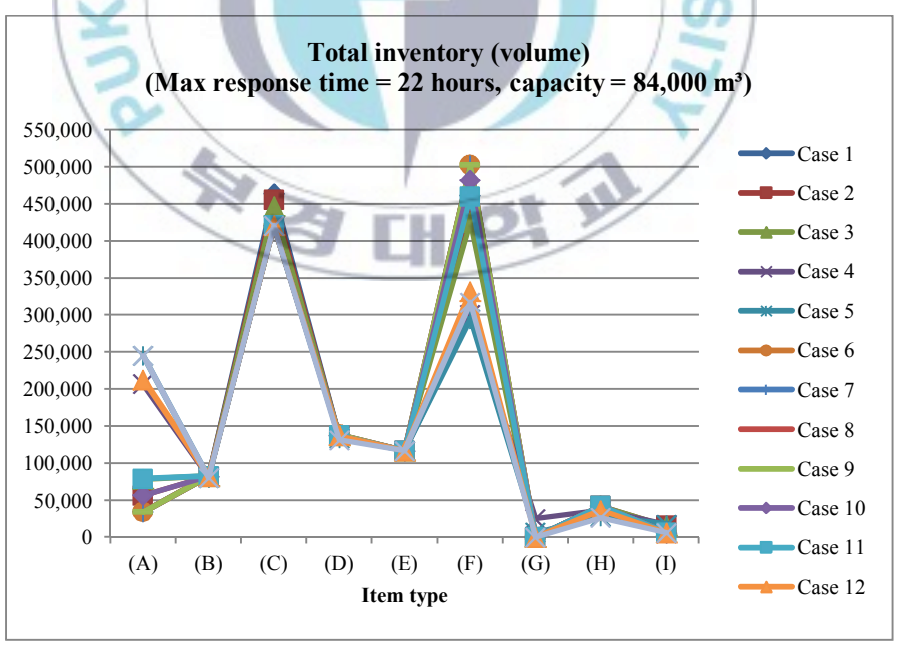


Figure 24a. Total inventory for each item type under varying budgets (maximum response time = 22 hours, capacity = 84,000 m³)

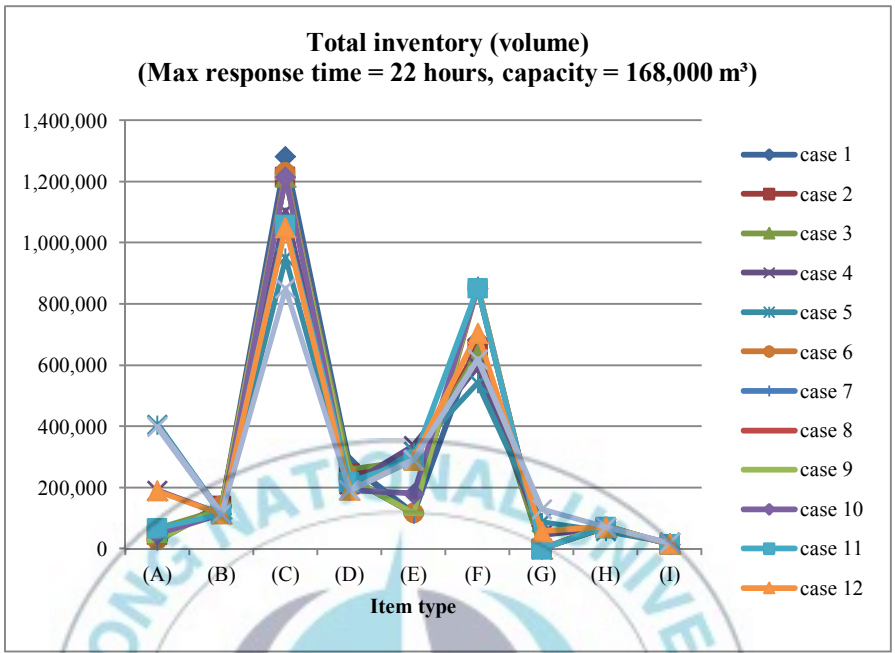


Figure 24b. Total inventory for each item type under varying budgets (maximum response time = 22 hours, capacity = 168,000 m³)

4.2.3 Sensitivity analysis for the proportion of relief demand satisfied

The next sensitivity analysis was performed on total proportion of relief demand satisfied by changing the maximum response time, budget, and capacity. Figure 25a and 25b show only the results under maximum response time of 7.3 and 22 hours. The rest of the results are seen in appendix G.

The analysis sensitivity was performed under maximum response time of 7.3 and 22 hours, the thirteen cases of budget scenario, and distribution center capacity of 84,000 m³. In these cases, item type I (lantern lamp) satisfied the most relief demand of the affected area. Despite its smaller volume spent in distribution centers, item type I satisfied the expected relief demand with total proportion as big as 32.87 or more than 99%. The next item would be item type E (blanket) with total proportion of 31.28 or more than 94%.

Zero proportion appeared on item type G (tent). Based on the same consideration as before, item type G has higher price and larger size comparing to another item. If the pre-disaster budget was increased into a very big number, there would be a small proportion of item G as big as 8.97 or around 27%.

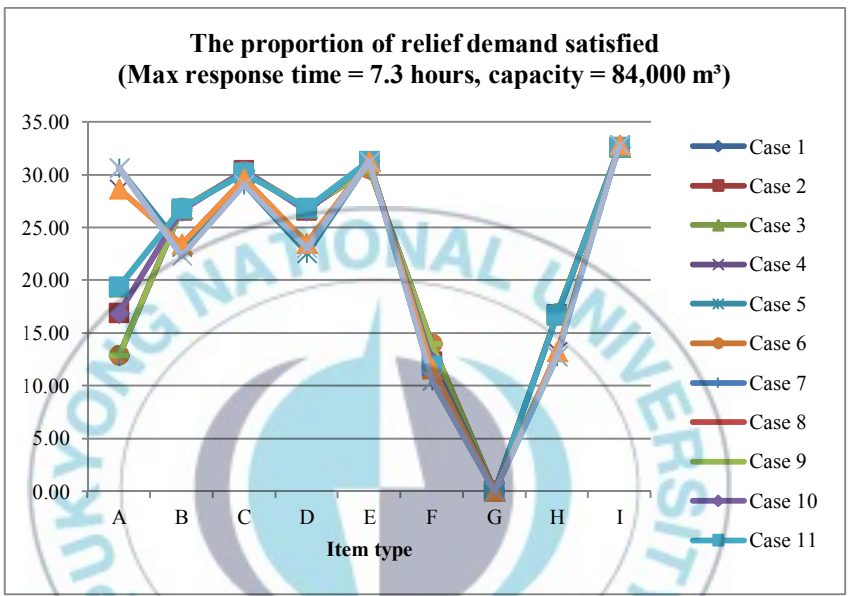


Figure 25a. The proportion of relief demand satisfied under varying budgets (maximum response time = 7.3 hours and capacity = 84,000 m³)

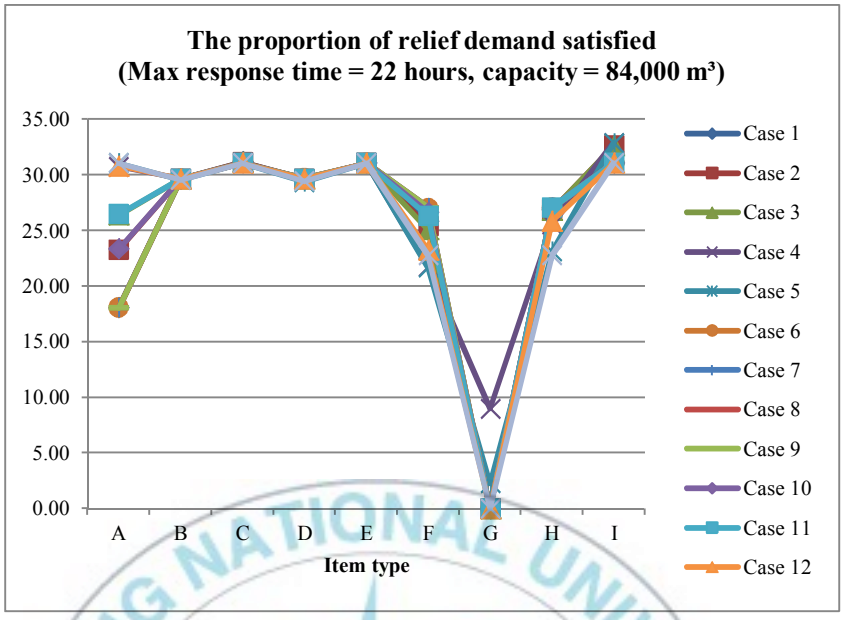


Figure 25b. The proportion of relief demand satisfied under varying budgets (maximum response time = 22 hours and capacity = 84,000 m³)

Figure 26a and 26b show the analysis sensitivity performed under distribution center capacity of 168,000 m³. In these cases, item type I (lantern lamp) still satisfied the most relief demand of the affected area with just slightly differences with item type C (rice) and E (blanket). Item type I satisfied the expected relief demand with total proportion as big as 33.00 or exactly 100% (demand for all item types were satisfied completely). The next item would be item type C and E with total proportion as big as 31.72 and 32.67 or more than 96% and 99%, respectively. Under distribution center capacity of 168,000 m³, maximum response time of 22 hours, and budget scenario of case 13, item type G (tent) reached the total proportion of 25.85 or around 78% (appendix G).

Based on the thirteen cases of budget scenario, the bigger the budget availability, the bigger the amount of inventory stocked in distribution centers and the bigger the total proportion of relief demand satisfied.

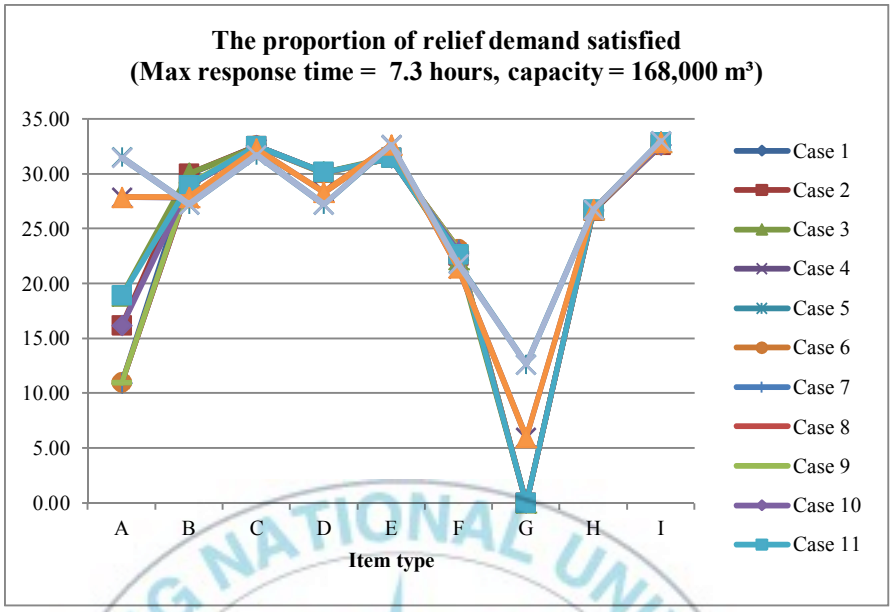


Figure 26a. The proportion of relief demand satisfied under varying budgets (maximum response time = 7.3 hours and capacity = 168,000 m³)

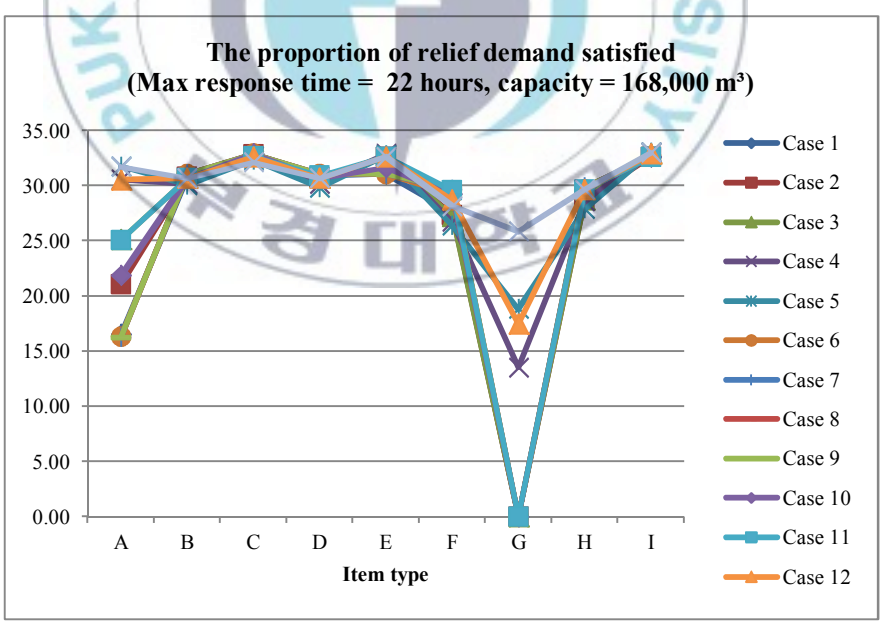


Figure 26b. Total proportion of relief demand satisfied under varying budgets (maximum response time = 22 hours and capacity = 168,000 m³)

Chapter 5. Conclusion and Future Research

Indonesia is one of the earthquake-prone countries in Asia. Therefore, the emergency disaster relief deployment of emergency products against the event of earthquake must be covered by the existing distribution centers. In this thesis, the emergency deployment model was proposed to maximize the total expected relief demand of disaster areas by considering the maximum response time, the capacity of distribution center, and the limitation of a budget. The decision of distribution centers to cover a disaster area and the amount of supplies to be stocked in each distribution center are simultaneously determined based on the model. The proposed model is applied to a real case with 33 disaster areas and 16 distribution centers in Indonesia. Then a sensitivity analysis is performed by changing the maximum response time, budgets, and distribution center capacity. Based on the model and real data, the optimal emergency disaster relief deployment planning is obtained within a short computation time.

There are several directions for future research. At first, various vehicle-types are not considered in this thesis. The transportation cost is mainly dependent upon the shipping volume of the each vehicle used. Therefore, vehicle-types should be considered to the model for a realistic analysis. In second, the probability of earthquake is necessary to determine to be more specifically. In current model, the probability of the earthquake is determined based on the earthquake events in each disaster area that ranges from 1.0 to 9.0 *Mw*. This determination can be more specific by tracking each disaster area hit by the most frequent and powerful earthquake. In third, the proposed single stage model in this thesis may not be flexible if the problem is getting more complex. Adding new variables or constraints may lead to another approach. In the last, accurate data

must be collected, considering the situation that occurs at present day. Data accuracy would support a better result, especially in determination of relief demand, number of item types, and expenditures.

REFERENCES

[1] Altay, N. and Green, W.G (2006), *OR/MS Research in Disaster Operations Management,* European Journal of Operational Research 175, pp. 474-493.

[2] Amin, S. and Goldstein, M. (2008), *Data Against Natural Disasters, Establishing Effective Systems for Relief, Recovery, and Reconstruction,* The International Bank for Reconstruction and Development/The world Bank, Washington, DC.

[3] Balcik B. and Beamon B.M (2008), *Facility Location in Humanitarian Relief*, International Journal of Logistics: Research and Applications, vol. 11, No.2, pp. 101-121.

[4] Beamon, B.M (2004), *Humanitarian Relief Chains: Issues and Challenges*, Proceedings of the 34th International Conference on Computers and Industrial Engineering.

[5] Beamon, B.M and Kotleba, S.A (2006), *Inventory Modelling for Complex Emergencies in Humanitarian Relief Operations*, International Journal of Logistics: Research and Applications, Vol. 9, No. 1, pp. 1-18.

[6] Blanchard, B.S (1992), *Logistics Engineering and Management*, 4th edition, Prentice-Hall International, Inc., New Jersey.

[7] Bowersox, D.J and Closs, D.J (1996), *Logistical Management: The Integrated Supply Chain Process*, McGraw-Hill Book Co., 1st edition, Singapore.

[8] Chang, M.S, Tseng, Y.L and Chen, J.W (2007), *A Scenario Planning Approach for the Flood Emergency Logistics Preparation Problem Under Uncertainty*, Transportation Research Part E 43, pp. 737-754.

[9] Coyle, J.J, Bardi, E.J and Langley Jr., C.J (2003), *The Management of Business Logistics: A Supply Chain Perspective,* 7th edition, South-Western Thomson Learning, Canada.

[10] Gatignon, A., Van Wassenhove, L. and Charles, A. (2010), *The Yogyakarta Earthquake: Humanitarian Relief through IFRC's Decentralized Supply Chain*, International Journal of Production Economics 126, pp. 102-110.

[11] Hale, T. and Moberg, C.R (2005), *Improving Supply Chain Disaster Preparedness, A Decision Process for Secure Site Location*, International Journal of Physical Distribution and Logistics Management, vol. 35, No. 3, pp.195-207.

[12] Irsyam, M. et. al. (2010), *Summary of the Study Result of Indonesia's Earthquake Map Revision Team 2010*, Record of Indonesia's Earthquake Map Revision Team. Available at: http://mpbi.org/content/ringkasan-hasil-studi-tim-revisi-peta-gempa-indonesia-2010

[13] Kovács, G. and Spens, K. (2009), *Identifying Challenges in Humanitarian Logistics,* International Journal of Physical Distribution and Logistics Management, vol. 39, No. 6, pp. 506-528.

[14] National Agency for Disaster Management of Indonesia (BNPB) (2009), *National Disaster Management Plan (2010-2014)*, e-book, National Agency for Disaster Management, Indonesia. Available at: http://www.bnpb.go.id/website/asp/pub.asp?p=4

[15] Oloruntoba, R. and Grey, R. (2006), *Humanitarian Aid: An Agile Supply Chain?,* Supply Chain management: an International Journal, pp.115-120.

[16] Ortuno, M.T, Tirado, G. and Vitoriano, B. (2010), *A Lexicographical Goal Programming Based Decision Support System for Logistics of Humanitarian Aid*, Invited Paper in TOP, Springer.

[17] Ozbay, K. and Ozguven, E.E (2007), *A Stochastic Humanitarian Inventory Control Model for Disaster Planning,* Presentation Material at the Transportation Research Board's 86th Annual Meeting, Washington.

[18] Ratick, S.; Meacham, B. and Aoyama, Y. (2008), *Locating Backup Facilities to Enhance Supply Chain Disaster Resilience,* Growth and Change, vol. 39, No. 4, pp. 642-666.

[19] Thomas, A. and Mizushima, M. (2005), *Logistics Training: Necessity or Luxury?,* Forced Migration Review, No. 22, pp. 60-1.

[20] Tovia, F. (2007), An Emergency Logistics Response System for Natural Disasters, International Journal of Logistics: Research and Applications, vol. 10, No.3, pp. 173-186.

[21] Tufekci, S. and Wallace, W.A (1998), *The Emerging Area of Emergency Management and Engineering,* IEEE Transactions on Engineering Management, Vol. 45, No.2.

[22] Van Wassenhove, L.N (2006), *Blackett Memorial Lecture Humanitarian Aid Logistics: Supply Chain Management in High Gear*, Journal of the Operational Research Society 57, pp. 475-489.

[23] Yi, W. and Ozdamar, L. (2007), *A Dynamic Logistics Coordination Model for Evacuation and Support in Disaster Response Activities*, European Journal of Operational Research 179, pp. 1177-1193.

A Stock Pre-positioning Model to Maximize the Total Expected Relief Demand of Disaster Areas

Prudensy Febreine

Department of Systems Management & Engineering,
The Graduate School, Pukyong National University

Abstract

Disaster Management that covers natural disasters such as earthquakes, tsunamis, floods, landslides, volcanic eruptions, or typhoons is required to identify hazard prone and formulate actions that should be prioritized. Ordinarily, natural disasters that come along with uncertainty factors are very difficult to predict. Some of them are even nearly impossible to predict. They come suddenly and without warning.

The complexity and uncertainty in performing emergency logistics response require a long-term preparation and planning. In this thesis, a stock pre-positioning model is proposed to support an emergency disaster relief response against the event of earthquake. In this model, a maximum response time limit, budget availability, multiple item types, and capacity restrictions are considered to maximize the total expected relief demand of disaster areas covered by existing distribution centers. The decision of distribution centers to cover a disaster area and the amount of supplies to be stocked in each distribution center are simultaneously determined based on the model. The proposed model is applied to a real case with 33 disaster areas and 16 distribution centers in Indonesia. Then a sensitivity analysis is performed by changing the maximum response time, budgets, and distribution center capacity. Finally, the conclusion and further research areas are remarked.

Keywords: Disaster relief, Disaster management, Humanitarian logistics, Stock pre-positioning.

재해지역의 총기대구호수요를 최대화하기 위한 재고품 사전배치 모형

프루덴시 페브레인

부경대학교 대학원 시스템경영공학과

요약문

지진, 쓰나미, 홍수, 산사태, 화산폭발 혹은 태풍과 같은 재해를 관리하기 위해서는 위험 성향의 파악과 우선순위가 매겨진 행동계획의 수립이 요구된다. 일반적으로 불확실성 요소들을 동반하는 자연재해는 예측하기 매우 어려우며 갑자기 그리고 아무런 경고 없이 다가온다.

그러므로 비상 로지스틱스 대응(emergency logistics response)에 있어 복잡성과 불확실성은 오랜 기간의 준비와 계획이 요구된다. 본 논문에서는 지진에 대비하여 비상 재해 구호 대응을 위해 재고품 사전배치(stock pre-positioning) 모형이 제안된다. 이 모형에서는 기존의 물류센터들에 의해 커버되는 재해지역의 총기대구호수요(total expected relief demand)를 최대화하기 위해 최대 대응시간, 예산, 다종의 구호물품 및 물류센터의 저장용량 제약들이 고려된다. 이 모형을 사용하여 재해지역을 커버하는 물류센터의 결정과 각 물류센터에서 저장되는 구호품목의 공급량을 동시에 결정한다. 제안된 모형은 인도네시아의 실제상황을 반영한 33개 재해지역과 16개 물류센터를 대상으로 적용된다. 또한 민감도 분석이 최대 대응시간, 예산 및 물류센터 용량의 변화를 통한 다양한 실험문제들을 대상으로 수행된다. 마지막으로 결론 및 추후 연구방향이 소개된다.

Acknowledgement

This thesis has been through a long process, big effort, and lots of struggle. The accomplishment of this thesis would not have been possible without the valuable contribution of all these great persons. Without them, I would have lost during my difficult times.

My outstanding supervisor, **Prof. Woon-Seek Lee—**I must give my high gratitude for his guidance, his time, his patience, his kindness, his understanding, and his trust for the last two years. *정말 감사합니다 이운식 교수님.*

I would like to thank all the Professors in Systems Management & Engineering Department (SME) of Pukyong National University (PKNU): **Prof. Byung-Nam Kim, Prof. Hyuck-Moo Kwon, Prof. Young Seok Ock, Prof. Pyeng-Mu Bark, Prof. Shie-Gheun Koh, Prof. Soo-Cheol Oh, Prof. Young-Jin Kim, and Prof. Minsoo Kim**—for all the guidance, the patience, the kindness, the understanding, the motivation, and the knowledge. It has been an honor to be the student of yours. Also, I would like to express my appreciation towards the examiners, **Prof. Pyung-Hoi Koo and Prof. Byung Soo Kim**—for their time, their advice, their suggestion, their comment, and their big support.

I would like to give my respectful gratitude towards my **Mom & Dad (*Papi & Mami*)**—for their trust (no one ever trusted me as much as they did), their tons of support, and their never-ending-love. And for someone who always live in my heart, my beloved late brother, **Christian Opit**—for all the inspiration he gave me. *I could keep moving forward because of you*.

My deepest thanks to all staffs in the Office of SME PKNU: **Ms. Hyun Jin Jeong, Ms. Han, and Ms. Lee**—for their help (of everything), their support (of everything), and their kindness (of everything).

My live in Korea during the last two years would not have been so

excited without the presence of all these persons. With them I could study more and more about Korea; I could smile, laugh, and cry from my heart; I could share and learn. Because of them, I had tons of beautiful memory and experience.

I wish to express my sincere thanks to all my Indonesian friends in SME PKNU: **Marsella, Karunia, Engelina, Mr. Agung and Mr. Tritya**—for being a best friend, a friend, a sister, a tutor, a family, and for never leaving me alone. My deepest thanks towards all my colleagues in the Graduate school of SME PKNU: **Mr. Yun Sik Park, Jang Hyeon Ae-*Onni*, Ji Won Park, Mrs. Young Sim Park, and others**—for being a nice friend, a tutor, a sister, a family, and for being so warm and supportive since the first time I arrived in PKNU…, until now.

I owe many thanks to all members of Operations Research laboratory: **Ju Ho Park, Bong Seok Hong, Hyun Min Park, Seng Gyu Cae, Seong Wook Seo, and others**—for being a good friend, for helping me a hundred times (maybe more, because I gave up counting since weeks ago ^^), for making me laugh, making me feel comfortable…, for teaching me many things about Korea, and for making me feel at home every time I was in the lab. My deepest thanks to all friends in SME PKNU: **Sun Heng Lee, Tae Gwon Kim, Yeong Tae Noh, and others**—for being a wonderful friend, a great Korean tutor, a superb translator, and for being supportive throughout the years.

Last but not least, I would like to thank my superiors and colleagues at my working place, De La Salle Catholic University (DLSU) of Manado: **Rector of DLSU-Pst. Revi Tanod, Sir Noldi Watuna, Maam Debby Paseru, Ms. Angreine Kewo, Sir Gerald Rawis, Maam Lianly Rompis, and others**—for giving me opportunities, for being very supportive, and for being a great motivator.

……., and above all others, **Jesus Christ**—for giving me an amazing parent, best professors, awesome friends, and everything that I need; for never letting me fall,

not even one second in my life… and for making this dream come true.

"From today and so on, I owe God an attitude of gratitude."

A. Demand for each disaster area based on Indonesia population in year 2010 (www.**bps**.go.id).

DISASTER AREA		TYPE OF PRODUCT								
		Medicine (box)	Instant food (box)	Rice (per kg)	Drinking water (box)	Blanket (unit)	Clothes (packet)	Tent (unit)	Mat (unit)	Lantern lamp (unit)
		A	B	C	D	E	F	G	H	I
Aceh*	**1**	4494410	898882	7280944	1498137	4494410	4494410	749068	749068	374534
North Sumatra*	**2**	12982204	2596441	21031170	4327401	12982204	12982204	2163701	2163701	1081850
Riau	**3**	5538367	1107673	8972155	1846122	5538367	5538367	923061	923061	461531
West Sumatra	**4**	4846909	969382	7851993	1615636	4846909	4846909	807818	807818	403909
Jambi	**5**	3092265	618453	5009469	1030755	3092265	3092265	515378	515378	257689
Riau Island*	**6**	1679163	335833	2720244	559721	1679163	1679163	279861	279861	139930
Bangka Belitung	**7**	1223296	244659	1981740	407765	1223296	1223296	203883	203883	101941
Bengkulu	**8**	1715518	343104	2779139	571839	1715518	1715518	285920	285920	142960
South Sumatra*	**9**	7450394	1490079	12069638	2483465	7450394	7450394	1241732	1241732	620866
Lampung*	**10**	7608405	1521681	12325616	2536135	7608405	7608405	1268068	1268068	634034
Banten*	**11**	10632166	2126433	17224109	3544055	10632166	10632166	1772028	1772028	886014
Jakarta	**12**	9607787	1921557	15564615	3202596	9607787	9607787	1601298	1601298	800649
West Java	**13**	43053732	8610746	69747046	14351244	43053732	43053732	7175622	7175622	3587811
Central Java	**14**	32382657	6476531	52459904	10794219	32382657	32382657	5397110	5397110	2698555
Yogyakarta*	**15**	3457491	691498	5601135	1152497	3457491	3457491	576249	576249	288124
East Java*	**16**	37476757	7495351	60712346	12492252	37476757	37476757	6246126	6246126	3123063
Bali	**17**	3890757	778151	6303026	1296919	3890757	3890757	648460	648460	324230
West Nusa Tenggara*	**18**	4500212	900042	7290343	1500071	4500212	4500212	750035	750035	375018

East Nusa Tenggara*	**19**	4683827	936765	7587800	1561276	4683827	4683827	780638	780638	390319
West Kalimantan	**20**	4395983	879197	7121492	1465328	4395983	4395983	732664	732664	366332
Central Kalimantan*	**21**	2212089	442418	3583584	737363	2212089	2212089	368682	368682	184341
South Kalimantan	**22**	3626616	725323	5875118	1208872	3626616	3626616	604436	604436	302218
East Kalimantan*	**23**	3553143	710629	5756092	1184381	3553143	3553143	592191	592191	296095
West Sulawesi	**24**	1158651	231730	1877015	386217	1158651	1158651	193109	193109	96554
South Sulawesi*	**25**	8034776	1606955	13016337	2678259	8034776	8034776	1339129	1339129	669565
South East Sulawesi	**26**	2232586	446517	3616789	744195	2232586	2232586	372098	372098	186049
Central Sulawesi*	**27**	2635009	527002	4268715	878336	2635009	2635009	439168	439168	219584
Gorontalo*	**28**	1040164	208033	1685066	346721	1040164	1040164	173361	173361	86680
North Sulawesi	**29**	2270596	454119	3678366	756865	2270596	2270596	378433	378433	189216
North Maluku	**30**	1038087	207617	1681701	346029	1038087	1038087	173015	173015	86507
Maluku*	**31**	1533506	306701	2484280	511169	1533506	1533506	255584	255584	127792
West Papua	**32**	760422	152084	1231884	253474	760422	760422	126737	126737	63369
Papua	**33**	2833381	566676	4590077	944460	2833381	2833381	472230	472230	236115

***consumption of rice per person per day = 0.54 Kg (1.62 Kg/person/3 days) = 25kg/15 persons/3 days**

***Tent (6 persons/tent)**

***Lantern lamp: 2 lamps for each tent**

***1 box of instant food is for 5 persons/3 days**

***1 box of drinking water is for 3 persons/3 days**

B. Data estimation of distance and expected time from distribution center 8 (Surabaya) to each disaster area (an example).

Assumption:
Helicopter speed: 260 km/hr
(Medium helicopter) Kerosene needed: 94.5 litre/hour
Kerosene price: Rp.6210/litre (0.7179 USD)

Disaster area		Capital city	Distance (KM)	Dist. centre	Expected time (hr)	Expected loading time (hr)	Total expected time (hr)	Kerosene needed (litre)
1	Aceh	Banda Aceh	2404	1	9.246	2	11.246	873.762
2	North Sumatra	Medan	1973	1	7.588	2	9.588	717.110
3	Riau	Pekanbaru	1526		5.869	2	7.869	554.642
4	West Sumatra	Padang	1543		5.935	2	7.935	560.821
5	Jambi	Jambi	1192		4.585	2	6.585	433.246
6	Riau Island	Tanjung Pinang	1304	1	5.015	2	7.015	473.954
7	Bangka-Belitung	Pangkal Pinang	923		3.550	2	5.550	335.475
8	Bengkulu	Bengkulu	1225		4.712	2	6.712	445.240
9	South Sumatra	Palembang	1006	1	3.869	2	5.869	365.642
10	Lampung	Bandar Lampung	851	1	3.273	2	5.273	309.306
11	Banten	Serang	738	1	2.838	2	4.838	268.235
12	***Jakarta**	***Jakarta**	664		2.554	2	4.554	241.338
13	West Java	Bandung	569		2.188	2	4.188	206.810
14	Central Java	Semarang	260		1.000	2	3.000	94.500
15	Yogyakarta	Yogyakarta	270	1	1.038	2	3.038	98.135
16	**East Java**	**Surabaya**	0	1	0.000	2	2.000	0.000

17	Bali	Denpasar	314		1.208	2	3.208	114.127
18	West Nusa Tenggara	Mataram	399	1	1.535	2	3.535	145.021
19	East Nusa Tenggara	Kupang	1244	1	4.785	2	6.785	452.146
20	West Kalimantan	Pontianak	846		3.254	2	5.254	307.488
21	Central Kalimantan	Palangkaraya	566	1	2.177	2	4.177	205.719
22	South Kalimantan	Banjarmasin	470		1.808	2	3.808	170.827
23	East Kalimantan	Samarinda	911	1	3.504	2	5.504	331.113
24	West Sulawesi	Mamuju	808		3.108	2	5.108	293.677
25	South Sulawesi	Makassar	774	1	2.977	2	4.977	281.319
26	South East Sulawesi	Kendari	1151		4.427	2	6.427	418.344
27	Central Sulawesi	Palu	1055	1	4.058	2	6.058	383.452
28	Gorontalo	Gorontalo	1421	1	5.465	2	7.465	516.479
29	North Sulawesi	Manado	1643		6.319	2	8.319	597.167
30	North Maluku	Ternate	1882		7.238	2	9.238	684.035
31	Maluku	Ambon	1800	1	6.923	2	8.923	654.231
32	West Papua	Manokwari	2472		9.508	2	11.508	898.477
33	Papua	Jayapura	3136		12.062	2	14.062	1,139.815

c. Probability of earthquake

Earthquake zone	Province	Capital city	Earthq events in 2004	Earthq events in 2005	Earthq events in 2006	Earthq events in 2007	Earthq events in 2008	Earthq events in 2009	Earthq events in 2010	Earthq events in 2011*)	Prob
6	**Aceh**	**Banda Aceh**	2	68	41	25	27	6	13	4	**0.639**
	North Sumatra	**Medan**	1	60	31	24	28	9	18	7	
	West Sumatra	**Padang**	1	30	11	33	43	30	30	8	
	Bengkulu	**Bengkulu**	9	9	15	56	41	13	24	5	
	Lampung	**Bandar Lampung**	0	2	9	2	9	1	6	0	
	Banten	**Serang**	0	4	2	3	1	1	2	0	
	Central Sulawesi	**Palu**	1	12	7	6	10	10	16	9	
	North Sulawesi	**Manado**	4	20	15	44	19	43	8	2	
	West Papua & Papua	**Manokwari & Jayapura**	10	10	18	25	13	42	59	5	
		TOTAL	28	215	149	218	191	155	176	40	
									Total	**1,172**	
									Average	**195**	
5	**West Java**	**Bandung**	3	17	17	14	15	10	29	8	**0.248**
	Bali	**Denpasar**	4	8	4	4	3	5	3	2	
	West Nusa Tenggara	**Mataram**	3	9	6	18	15	10	7	1	
	East Nusa Tenggara	**Kupang**	7	3	16	7	10	10	13	3	
	Gorontalo	**Gorontalo**	0	1	7	1	5	5	6	1	
	North	**Ternate &**	4	10	23	47	22	15	19	5	

	Maluku & Maluku	**Ambon**									
		TOTAL	21	48	73	91	70	55	77	20	
									Total	**455**	
									Average	**76**	
4	**Riau**	**Pekanbaru**	0	0	0	0	0	0	0	0	**0.109**
	Jambi	**Jambi**	0	0	0	7	0	1	0	0	
	South Sumatra	**Palembang**	1	0	2	0	1	0	0	0	
	Central Java	**Semarang**	1	1	2	5	4	2	4	1	
	Yogyakarta	**Yogyakarta**	1	0	20	5	13	9	14	1	
	East Java	**Surabaya**	4	8	7	13	7	1	10	6	
	West Sulawesi	**Mamuju**	0	4	2	1	0	0	1	0	
	South Sulawesi	**Makassar**	0	0	1	0	2	2	4	13	
	South East Sulawesi	**Kendari**	0	1	7	0	4	4	3	0	
		TOTAL	7	14	41	31	31	19	36	21	
									Total	**200**	
									Average	**33**	
3	**Jakarta**	**Jakarta**	0	1	0	0	0	0	0	0	**0.003**
		TOTAL	0	1	0	0	0	0	0	0	
									Total	**1**	
									Average	**1**	
2	**South Kalimantan**	**Banjarmasin**	0	0	0	0	0	0	0	0	**0.003**
	East Kalimantan	**Samarinda**	0	0	1	1	1	3	0	0	

		TOTAL	0	0	1	1	1	3	0	0	
									Total	**6**	
									Average	**2**	
1	**Riau Island**	**Tanjung Pinang**	0	0	0	0	0	0	0	0	**0.003**
	Bangka-Belitung	**Pangkal Pinang**	0	0	0	0	0	0	0	0	
	West Kalimantan	**Pontianak**	0	0	0	0	0	0	0	0	
	Central Kalimantan	**Palangkaraya**	0	0	0	0	0	0	1	0	
		TOTAL	0	0	0	0	0	0	1	0	
									Total	**1**	
									Average	**0**	
			56	**278**	**264**	**341**	**293**	**232**	**290**	**81**	**1.00**
										1,842	

D. Total distribution center to cover relief demand of each disaster area

	Disaster Area																Resp time (hours)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
	Aceh	North Sum	Riau	West Sum	Jambi	Riau Island	Bangka Bel	Bgklu	South Sum	Lmpg	Banten	Jkt	West Java	Central Java	Yogya karta	East Java	
Total distribution center	3	6	7	7	9	9	10	9	9	9	10	9	10	11	11	12	**7.3**
	4	**6**	**9**	**9**	**10**	**10**	**13**	**9**	**11**	**10**	**11**	**12**	**12**	**12**	**12**	**13**	**8**
	5	9	12	11	11	14	14	13	14	14	15	15	15	15	15	15	**10**
	10	13	14	14	15	15	16	15	15	16	16	16	16	16	16	16	**12**
	15	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	**20**
	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	**22**

	Disaster Area																	Resp time (hours)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
	Bali	West Nusa Teng	East Nusa Teng	West Kal	Cntral Kal	South Kal	East Kal	West Sul	South Sul	South East Sul	Central Sul	Goron talo	North Sul	North Mal	Mal	West Papua	Papua	
Total distribution center	12	11	9	12	13	13	10	10	10	9	10	8	7	6	6	2	1	**7.3**
	12	**13**	**10**	**13**	**13**	**13**	**14**	**12**	**11**	**10**	**10**	**9**	**8**	**7**	**7**	**2**	**1**	**8**
	14	14	11	15	15	15	14	14	14	13	14	14	10	9	10	6	2	**10**
	15	15	14	16	16	16	16	15	15	14	15	14	14	14	12	9	5	**12**
	16	16	16	16	16	16	16	16	16	16	16	16	16	16	15	14	10	**16**
	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	14	**20**
	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	**22**

E. Sensitivity analysis of total distribution center to cover disaster areas

DISASTER AREA		RESP TIME (hours)	DISTRIBUTION CENTER																Total Dist Center
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	Aceh	7.3	*	*	*														3
		8	*	*	*	*													4
		10	*	*	*	*	*												5
		12	*	*	*	*	*	*	*	*				*	*				10
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		15
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
2	North Sumatra	7.3	*	*	*	*	*	*											6
		8	*	*	*	*	*	*											6
		10	*	*	*	*	*	*	*	*				*					9
		12	*	*	*	*	*	*	*	*	*	*		*	*	*			13
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
3	Riau	7.3	*	*	*	*	*	*	*										7
		8	*	*	*	*	*	*	*	*				*					9
		10	*	*	*	*	*	*	*	*	*			*	*	*			12
		12	*	*	*	*	*	*	*	*	*	*		*	*	*	*		14
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
4	West Sumatra	7.3	*	*	*	*	*	*	*										7
		8	*	*	*	*	*	*	*	*				*					9
		10	*	*	*	*	*	*	*	*	*			*	*				11
		12	*	*	*	*	*	*	*	*	*	*		*	*	*	*		14
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
5	Jambi	7.3	*	*	*	*	*	*	*	*				*					9
		8	*	*	*	*	*	*	*	*				*	*				10
		10	*	*	*	*	*	*	*	*				*	*	*			11
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		15
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16

6	Riau Island	7.3	*	*	*	*	*	*	*	*				*					9
		8	*	*	*	*	*	*	*	*				*	*				10
		10	*	*	*	*	*	*	*	*	*	*		*	*	*	*		14
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		15
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
7	Bangka Belitung	7.3		*	*	*	*	*	*	*	*			*	*				10
		8	*	*	*	*	*	*	*	*	*	*		*	*	*			13
		10	*	*	*	*	*	*	*	*	*	*		*	*	*	*		14
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
8	Bengkulu	7.3	*	*	*	*	*	*	*	*				*					9
		8	*	*	*	*	*	*	*	*				*					9
		10	*	*	*	*	*	*	*	*	*	*		*	*	*			13
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		15
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
9	South Sumatra	7.3		*	*	*	*	*	*	*	*			*					9
		8	*	*	*	*	*	*	*	*	*			*	*				11
		10	*	*	*	*	*	*	*	*	*	*		*	*	*	*		14
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		15
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
10	Lampung	7.3		*	*	*	*	*	*	*	*			*					9
		8		*	*	*	*	*	*	*	*			*	*				10
		10	*	*	*	*	*	*	*	*	*	*		*	*	*	*		14
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
11	Banten	7.3		*	*	*	*	*	*	*	*	*		*					10
		8		*	*	*	*	*	*	*	*	*		*	*				11
		10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		15
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16

12	Jakarta	7.3			*	*	*	*	*	*	*			*	*				9
		8		*	*	*	*	*	*	*	*	*		*	*	*			12
		10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		15
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
13	West Java	7.3			*	*	*	*	*	*	*	*		*	*				10
		8		*	*	*	*	*	*	*	*	*		*	*	*			12
		10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		15
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
14	Central Java	7.3			*	*	*	*	*	*	*	*		*	*	*			11
		8			*	*	*	*	*	*	*	*		*	*	*			12
		10		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
15	Yogyakarta	7.3			*	*	*	*	*	*	*	*		*	*	*			11
		8			*	*	*	*	*	*	*	*	*	*	*	*			12
		10		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
16	East Java	7.3			*	*	*	*	*	*	*	*		*	*	*			12
		8			*	*	*	*	*	*	*	*	*	*	*	*	*		13
		10		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
17	Bali	7.3				*	*	*	*	*	*	*	*	*	*	*	*		12
		8				*	*	*	*	*	*	*	*	*	*	*	*		12
		10			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		12		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16

18	West Nusa Tenggara	7.3					*	*	*	*	*	*	*	*	*	*	*		11
		8				*	*	*	*	*	*	*	*	*	*	*	*	*	13
		10			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		12		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
19	East Nusa Tenggara	7.3								*	*	*	*	*	*	*	*	*	9
		8						*	*	*	*	*	*	*	*	*	*	*	10
		10					*	*	*	*	*	*	*	*	*	*	*	*	11
		12			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
20	West Kalimantan	7.3		*	*	*	*	*	*	*	*	*	*	*	*	*			12
		8		*	*	*	*	*	*	*	*	*		*	*	*	*		13
		10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		15
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
21	Central Kalimantan	7.3			*	*	*	*	*	*	*	*	*	*	*	*	*		13
		8			*	*	*	*	*	*	*	*	*	*	*	*	*		13
		10		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
22	South Kalimantan	7.3			*	*	*	*	*	*	*	*	*	*	*	*	*		13
		8			*	*	*	*	*	*	*	*	*	*	*	*	*		13
		10		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
23	East Kalimantan	7.3							*	*	*	*	*	*	*	*	*	*	10
		8			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		10			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16

		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
24	West Sulawesi	7.3							*	*	*	*	*	*	*	*	*	*	10
		8					*	*	*	*	*	*	*	*	*	*	*	*	12
		10			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		12		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
25	South Sulawesi	7.3							*	*	*	*	*	*	*	*	*	*	10
		8						*	*	*	*	*	*	*	*	*	*	*	11
		10			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		12		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
26	South East Sulawesi	7.3								*	*	*	*	*	*	*	*	*	9
		8							*	*	*	*	*	*	*	*	*	*	10
		10				*	*	*	*	*	*	*	*	*	*	*	*	*	13
		12			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
27	Central Sulawesi	7.3							*	*	*	*	*	*	*	*	*	*	10
		8							*	*	*	*	*	*	*	*	*	*	10
		10			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		12		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
28	Gorontalo	7.3									*	*	*	*	*	*	*	*	8
		8								*	*	*	*	*	*	*	*	*	9
		10			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		12			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
29	North Sulawesi	7.3										*	*	*	*	*	*	*	7
		8									*	*	*	*	*	*	*	*	8
		10							*	*	*	*	*	*	*	*	*	*	10
		12			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16

		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
30	North Maluku	7.3										*	*		*	*	*	*	6
		8										*	*	*	*	*	*	*	7
		10								*	*	*	*	*	*	*	*	*	9
		12			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
31	Maluku	7.3										*	*		*	*	*	*	6
		8									*	*	*		*	*	*	*	7
		10							*	*	*	*	*	*	*	*	*	*	10
		12					*	*	*	*	*	*	*	*	*	*	*	*	12
		16		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
32	West Papua	7.3															*	*	2
		8															*	*	2
		10										*	*		*	*	*	*	6
		12								*	*	*	*	*	*	*	*	*	9
		16			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
33	Papua	7.3																*	1
		8																*	1
		10															*	*	2
		12										*	*			*	*	*	5
		16						*	*	*	*	*	*	*	*	*	*	*	10
		20			*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
		22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
		SUM	33	33	33	32	31	30	28	26	19	17	14	26	22	19	16	12	

F. Sensitivity analysis of total inventory

(Capacity of each distribution centre = 84,000 m³)

Resp. time (hours)	Pre-disaster budget ($)	Post-disaster budget ($)	Total expected relief demand (unit)	Total inventory (volume)								
				Medicine	Instant food	Rice	Drinking water	Blanket	Clothes	Tent	Mat	Lantern Lamp
				(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
7.3	**857,317,919.08**	**116,589,595.38**	**17,165,980.00**	**33,214.35**	**93,382.09**	**598,727.20**	**155,636.90**	**145,122.30**	**276,706.50**	**0.00**	**24,703.20**	**16,507.52**
	1,285,976,878.61	116,589,595.38	17,667,530.00	53,939.77	93,382.09	573,359.70	155,636.90	189,152.80	237,318.10	0.00	24,703.20	16,507.52
	1,714,635,838.15	116,589,595.38	18,062,110.00	76,213.50	93,382.09	553,880.90	155,636.90	189,152.80	234,523.20	0.00	24,703.20	16,507.52
	4,286,589,595.38	116,589,595.38	19,444,830.00	209,609.40	55,689.17	520,175.90	93,703.96	193,610.20	229,927.60	0.00	21,286.86	19,996.95
	8,573,179,190.75	116,589,595.38	19,529,000.00	362,528.60	55,689.17	410,106.10	84,423.23	189,152.80	200,816.30	0.00	21,286.86	19,996.95
	857,317,919.08	174,884,393.06	17,165,980.00	33,214.35	93,382.09	598,727.20	155,636.90	145,122.30	276,706.50	0.00	24,703.20	16,507.52
	857,317,919.08	233,179,190.75	17,165,980.00	33,214.35	93,382.09	598,727.20	155,636.90	145,122.30	276,706.50	0.00	24,703.20	16,507.52
	857,317,919.08	582,947,976.88	17,165,980.00	33,214.35	93,382.09	598,727.20	155,636.90	145,122.30	276,706.50	0.00	24,703.20	16,507.52
	857,317,919.08	1,165,895,953.75	17,165,980.00	33,214.35	93,382.09	598,727.20	155,636.90	145,122.30	276,706.50	0.00	24,703.20	16,507.52
	1,285,976,878.61	174,884,393.06	17,667,530.00	53,939.77	93,382.09	573,359.70	155,636.90	189,152.80	237,318.10	0.00	24,703.20	16,507.52
	1,714,635,838.15	233,179,190.75	18,062,110.00	76,213.50	93,382.09	553,880.90	155,636.90	189,152.80	234,523.20	0.00	24,703.20	16,507.52
	4,286,589,595.38	582,947,976.88	19,444,830.00	209,609.40	55,689.17	520,175.90	93,703.96	193,610.20	229,927.60	0.00	21,286.86	19,996.95
	8,573,179,190.75	1,165,895,953.75	19,529,000.00	362,528.60	48,602.27	410,106.10	91,510.14	189,152.80	200,816.30	0.00	21,286.86	19,996.95
8	**857,317,919.08**	**116,589,595.38**	**17,979,240.00**	**33,235.02**	**82,170.77**	**538,295.00**	**142,561.60**	**137,843.90**	**356,910.00**	**0.00**	**36,475.88**	**16,507.52**
	1,285,976,878.61	116,589,595.38	18,567,630.00	55,573.15	82,170.77	543,905.60	136,951.30	137,843.90	334,571.80	0.00	36,475.88	16,507.52
	1,714,635,838.15	116,589,595.38	19,059,470.00	77,106.58	82,170.77	522,755.30	136,951.30	158,994.30	313,038.40	0.00	36,475.88	16,507.52
	4,286,589,595.38	116,589,595.38	20,404,920.00	209,322.50	68,908.48	423,730.20	114,847.50	189,152.80	290,724.10	0.00	24,703.20	22,611.16
	8,573,179,190.75	116,589,595.38	20,441,220.00	268,004.90	68,908.48	405,945.60	114,847.50	189,152.80	249,826.40	0.00	24,703.20	22,611.16
	857,317,919.08	174,884,393.06	17,979,240.00	33,235.02	82,170.77	538,295.40	142,561.60	137,843.90	356,910.00	0.00	36,475.88	16,507.52
	857,317,919.08	233,179,190.75	17,979,240.00	33,235.02	82,170.77	538,295.40	142,561.60	137,843.90	356,910.00	0.00	36,475.88	16,507.52
	857,317,919.08	582,947,976.88	17,979,240.00	33,235.02	82,170.77	538,295.40	142,561.60	137,843.90	356,910.00	0.00	36,475.88	16,507.52
	857,317,919.08	1,165,895,953.75	17,979,240.00	33,235.02	82,170.77	538,295.40	142,561.60	137,843.90	356,910.00	0.00	36,475.88	16,507.52
	1,285,976,878.61	174,884,393.06	18,567,630.00	55,573.15	82,170.77	543,905.60	136,951.30	137,843.90	334,571.80	0.00	36,475.88	16,507.52
	1,714,635,838.15	233,179,190.75	19,059,470.00	77,106.58	82,170.77	522,755.30	136,951.30	158,994.30	313,038.40	0.00	36,475.88	16,507.52

	4,286,589,595.38	582,947,976.88	20,404,920.00	209,322.50	68,908.48	423,730.20	114,847.50	189,152.80	290,724.10	0.00	24,703.20	22,611.16
	8,573,179,190.75	1,165,895,953.75	20,441,220.00	268,004.90	68,908.48	405,945.60	114,847.50	189,152.80	249,826.40	0.00	24,703.20	22,611.16
10	**857,317,919.08**	**116,589,595.38**	**20,015,700.00**	**33,293.10**	**82,170.77**	**573,531.50**	**152,078.90**	**142,340.30**	**308,930.20**	**0.00**	**36,475.88**	**15,179.37**
	1,285,976,878.61	116,589,595.38	20,729,620.00	55,657.77	82,170.77	583,084.50	142,525.90	142,340.30	294,857.50	0.00	28,183.90	15,179.37
	1,714,635,838.15	116,589,595.38	21,318,170.00	77,942.71	82,170.77	564,280.30	142,525.90	142,340.30	294,857.50	0.00	24,703.20	15,179.37
	4,286,589,595.38	116,589,595.38	22,786,290.00	209,632.60	80,464.27	435,174.60	135,815.70	187,364.90	254,079.70	0.00	21,286.86	20,181.44
	8,573,179,190.75	116,589,595.38	22,810,170.00	295,291.30	82,170.77	349,515.90	134,109.20	187,364.90	254,079.70	0.00	21,286.86	20,181.44
	857,317,919.08	174,884,393.06	20,021,410.00	33,293.10	82,170.77	573,531.50	152,078.90	142,340.30	308,930.20	0.00	36,475.88	15,179.37
	857,317,919.08	233,179,190.75	20,021,410.00	33,293.10	82,170.77	573,531.50	152,078.90	142,340.30	308,930.20	0.00	36,475.88	15,179.37
	857,317,919.08	582,947,976.88	20,021,410.00	33,293.10	82,170.77	573,531.50	152,078.90	142,340.30	308,930.20	0.00	36,475.88	15,179.37
	857,317,919.08	1,165,895,953.75	20,021,410.00	33,293.10	82,170.77	573,531.50	152,078.90	142,340.30	308,930.20	0.00	36,475.88	15,179.37
	1,285,976,878.61	174,884,393.06	20,735,270.00	55,657.77	82,170.77	583,084.50	142,525.90	142,340.30	294,857.50	0.00	28,183.90	15,179.37
	1,714,635,838.15	233,179,190.75	21,323,240.00	77,942.71	82,170.77	564,280.30	142,525.90	142,340.30	294,857.50	0.00	24,703.20	15,179.37
	4,286,589,595.38	582,947,976.88	22,791,330.00	209,632.60	80,464.27	435,174.60	135,815.70	187,364.90	254,079.70	0.00	21,286.86	20,181.44
	8,573,179,190.75	1,165,895,953.75	22,814,930.00	295,291.30	80,464.27	349,515.90	135,815.70	187,364.90	254,079.70	0.00	21,286.86	20,181.44
12	**857,317,919.08**	**116,589,595.38**	**21,136,780.00**	**34,443.64**	**82,170.77**	**463,857.50**	**136,951.30**	**116,839.80**	**461,462.00**	**0.00**	**42,189.47**	**6,085.41**
	1,285,976,878.61	116,589,595.38	21,899,580.00	56,115.58	82,170.77	454,741.50	136,951.30	116,839.80	439,812.10	0.00	42,189.47	15,179.37
	1,714,635,838.15	116,589,595.38	22,508,030.00	78,445.63	82,170.77	454,162.30	136,951.30	116,839.80	418,115.70	0.00	42,135.08	15,179.37
	4,286,589,595.38	116,589,595.38	24,078,360.00	209,302.40	82,170.77	420,623.40	136,951.30	138,954.70	294,857.50	11,158.77	32,414.01	17,567.23
	8,573,179,190.75	116,589,595.38	24,139,260.00	244,974.20	82,170.77	420,623.40	136,951.30	119,607.70	294,857.50	2,544.71	24,703.20	17,567.23
	857,317,919.08	174,884,393.06	21,309,920.00	34,311.79	82,170.77	420,623.40	136,951.30	116,839.80	503,573.70	0.00	43,443.78	6,085.41
	857,317,919.08	233,179,190.75	21,309,920.00	34,311.79	82,170.77	420,623.40	136,951.30	116,839.80	503,573.70	0.00	43,443.78	6,085.41
	857,317,919.08	582,947,976.88	21,309,920.00	34,311.79	82,170.77	420,623.40	136,951.30	116,839.80	503,573.70	0.00	43,443.78	6,085.41
	857,317,919.08	1,165,895,953.75	21,309,920.00	34,311.79	82,170.77	420,623.40	136,951.30	116,839.80	503,573.70	0.00	43,443.78	6,085.41
	1,285,976,878.61	174,884,393.06	22,071,100.00	56,014.15	82,170.77	420,623.40	136,951.30	116,839.80	474,031.70	0.00	42,189.47	15,179.37
	1,714,635,838.15	233,179,190.75	22,684,300.00	78,345.78	82,170.77	420,623.40	136,951.30	116,839.80	451,700.10	0.00	42,189.47	15,179.37
	4,286,589,595.38	582,947,976.88	24,247,980.00	207,191.40	82,170.77	420,623.40	136,951.30	121,678.00	295,994.70	25,347.40	36,475.88	17,567.23
	8,573,179,190.75	1,165,895,953.75	24,303,170.00	244,974.20	82,170.77	420,623.40	136,951.30	121,678.00	294,857.50	474.45	24,703.20	17,567.23
16	**857,317,919.08**	**116,589,595.38**	**21,577,260.00**	**34,444.45**	**82,170.77**	**464,128.60**	**136,951.30**	**116,839.80**	**461,190.10**	**0.00**	**42,189.47**	**6,085.41**
	1,285,976,878.61	116,589,595.38	22,407,190.00	56,117.78	82,170.77	455,482.60	136,951.30	116,839.80	439,068.90	0.00	42,189.47	15,179.37
	1,714,635,838.15	116,589,595.38	23,017,220.00	78,423.46	82,170.77	446,706.50	136,951.30	116,839.80	425,593.70	0.00	42,135.08	15,179.37
	4,286,589,595.38	116,589,595.38	24,412,670.00	207,359.60	82,170.77	420,623.40	136,951.30	116,839.80	300,664.60	25,347.40	36,475.88	17,567.23

	8,573,179,190.75	116,589,595.38	24,482,810.00	244,974.20	80,464.27	420,623.40	134,107.10	116,839.80	294,857.50	5,820.85	28,745.61	17,567.23
	857,317,919.08	174,884,393.06	21,938,120.00	34,317.38	82,170.77	420,623.40	138,200.00	116,839.80	503,573.70	0.00	42,189.47	6,085.41
	857,317,919.08	233,179,190.75	22,054,990.00	34,318.55	82,170.77	420,623.40	138,848.10	116,839.80	502,924.50	0.00	42,189.47	6,085.41
	857,317,919.08	582,947,976.88	22,054,990.00	34,318.55	82,170.77	420,623.40	138,848.10	116,839.80	502,924.50	0.00	42,189.47	6,085.41
	857,317,919.08	1,165,895,953.75	22,054,990.00	34,318.55	82,170.77	420,623.40	138,848.10	116,839.80	502,924.50	0.00	42,189.47	6,085.41
	1,285,976,878.61	174,884,393.06	22,782,020.00	56,646.89	82,170.77	420,623.40	136,951.30	116,839.80	482,547.30	0.00	42,135.07	6,085.41
	1,714,635,838.15	233,179,190.75	23,510,080.00	78,978.52	82,170.77	420,623.40	136,951.30	116,839.80	460,215.70	0.00	42,135.08	6,085.41
	4,286,589,595.38	582,947,976.88	24,838,930.00	212,983.30	82,170.77	420,623.40	136,951.30	116,839.80	331,870.10	0.00	36,475.88	6,085.41
	8,573,179,190.75	1,165,895,953.75	24,893,100.00	244,974.20	77,751.79	420,623.40	134,107.10	116,839.80	317,055.30	0.00	26,562.94	6,085.41
	857,317,919.08	**116,589,595.38**	**21,577,260.00**	**34,444.45**	**82,170.77**	**464,128.50**	**136,951.30**	**116,839.80**	**461,190.30**	**0.00**	**42,189.47**	**6,085.41**
	1,285,976,878.61	116,589,595.38	22,407,190.00	56,117.78	82,170.77	455,482.60	136,951.30	116,839.80	439,068.90	0.00	42,189.47	15,179.37
	1,714,635,838.15	116,589,595.38	23,017,220.00	78,423.46	82,170.77	446,706.50	136,951.30	116,839.80	425,593.70	0.00	42,135.07	15,179.37
	4,286,589,595.38	116,589,595.38	24,413,010.00	207,359.60	82,170.77	420,623.40	136,951.30	116,839.80	300,664.60	25,347.40	36,475.88	17,567.23
	8,573,179,190.75	116,589,595.38	24,485,250.00	244,974.20	80,464.27	420,623.40	134,107.10	116,839.80	294,857.50	6,391.73	28,174.73	17,567.23
	857,317,919.08	174,884,393.06	21,953,400.00	34,318.55	82,170.77	420,623.40	138,848.10	116,839.80	502,924.50	0.00	42,189.47	6,085.41
20	857,317,919.08	233,179,190.75	22,054,990.00	34,318.55	82,170.77	420,623.40	138,848.10	116,839.80	502,924.50	0.00	42,189.47	6,085.41
	857,317,919.08	582,947,976.88	22,054,990.00	34,318.55	82,170.77	420,623.40	138,848.10	116,839.80	502,924.50	0.00	42,189.47	6,085.41
	857,317,919.08	1,165,895,953.75	22,054,990.00	34,318.55	82,170.77	420,623.40	138,848.10	116,839.80	502,924.50	0.00	42,189.47	6,085.41
	1,285,976,878.61	174,884,393.06	22,797,610.00	56,646.89	82,170.77	420,623.40	136,951.30	116,839.80	482,547.30	0.00	42,135.07	6,085.41
	1,714,635,838.15	233,179,190.75	23,510,080.00	78,978.52	82,170.77	420,623.40	136,951.30	116,839.80	460,215.70	0.00	42,135.07	6,085.41
	4,286,589,595.38	582,947,976.88	24,838,930.00	212,983.30	82,170.77	420,623.40	136,951.30	116,839.80	331,870.10	0.00	36,475.88	6,085.41
	8,573,179,190.75	1,165,895,953.75	24,893,100.00	244974.20	80464.27	420,623.40	131,394.60	116,839.80	317,055.30	0.00	26,562.94	6,085.41
22	**857,317,919.08**	**116,589,595.38**	**21,577,260.00**	**34,444.45**	**82,170.77**	**464,128.50**	**136,951.30**	**116,839.80**	**461,190.30**	**0.00**	**42,189.47**	**6,085.41**
	1,285,976,878.61	116,589,595.38	22,407,190.00	56,117.78	82,170.77	455,482.60	136,951.30	116,839.80	439,068.90	0.00	42,189.47	15,179.37
	1,714,635,838.15	116,589,595.38	23,017,220.00	78,423.46	82,170.77	446,706.50	136,951.30	116,839.80	425,593.70	0.00	42,135.07	15,179.37
	4,286,589,595.38	116,589,595.38	24,413,010.00	207,359.60	82,170.77	420,623.40	136,951.30	116,839.80	300,664.60	25,347.40	36,475.88	17,567.23
	8,573,179,190.75	116,589,595.38	24,485,250.00	244,974.20	80,464.27	420,623.40	134,107.10	116,839.80	294,857.50	6,391.73	28,174.73	17,567.23
	857,317,919.08	174,884,393.06	21,953,400.00	34,318.55	82,170.77	420,623.40	138,848.10	116,839.80	502,924.50	0.00	42,189.47	6,085.41
	857,317,919.08	233,179,190.75	22,054,990.00	34,318.55	82,170.77	420,623.40	138,848.10	116,839.80	502,924.50	0.00	42,189.47	6,085.41
	857,317,919.08	582,947,976.88	22,054,990.00	34,318.55	82,170.77	420,623.40	138,848.10	116,839.80	502,924.50	0.00	42,189.47	6,085.41
	857,317,919.08	1,165,895,953.75	22,054,990.00	34,318.55	82,170.77	420,623.40	138,848.10	116,839.80	502,924.50	0.00	42,189.47	6,085.41
	1,285,976,878.61	174,884,393.06	22,797,620.00	56,646.89	82,170.77	420,623.40	136,951.30	116,839.80	482,547.30	0.00	42,135.08	6,085.41

	1,714,635,838.15	233,179,190.75	23,510,080.00	78,978.52	82,170.77	420,623.40	136,951.30	116,839.80	460,215.70	0.00	42,135.07	6,085.41
	4,286,589,595.38	582,947,976.88	24,838,930.00	212,983.30	82,170.77	420,623.40	136,951.30	116,839.80	331,870.10	0.00	36,475.88	6,085.41
	8,573,179,190.75	1,165,895,953.75	24,893,100.00	244,974.20	80,464.27	420,623.40	131,394.60	116,839.80	317,055.30	0.00	26,562.94	6,085.41

(Capacity of each distribution centre = 168,000 m³)

Response time (hours)	Pre-disaster budget ($)	Post-disaster budget ($)	Total expected relief demand (unit)	Total inventory (volume)								
				Medicine (A)	Instant food (B)	Rice (C)	Drinking water (D)	Blanket (E)	Clothes (F)	Tent (G)	Mat (H)	Lantern Lamp (I)
7.3	**857,317,919.08**	**116,589,595.38**	**21,866,000.00**	**26,448.70**	**179,928.90**	**1,238,727.00**	**305,086.40**	**189,152.80**	**647,824.30**	**0.00**	**84,324.54**	**16,507.52**
	1,285,976,878.61	116,589,595.38	22,481,760.00	48,714.14	179,928.90	1,216,461.00	305,086.40	189,152.80	647,824.30	0.00	84,324.54	16,507.52
	1,714,635,838.15	116,589,595.38	22,990,040.00	70,373.56	179,928.90	1,180,898.00	305,086.40	200,669.00	647,824.30	0.00	84,324.54	18,895.38
	4,286,589,595.38	116,589,595.38	25,200,570.00	195,279.10	110,399.70	1,157,892.00	215,902.60	316,944.30	563,014.80	25,347.40	84,324.54	18,895.38
	8,573,179,190.75	116,589,595.38	25,910,540.00	405,855.80	102,931.90	961,397.60	171,553.20	316,944.30	535,649.30	87,833.60	84,324.54	21,509.58
	857,317,919.08	174,884,393.06	21,900,610.00	26,551.81	147,272.30	1,271,280.00	305,086.40	189,152.80	647,824.30	0.00	84,324.54	16,507.52
	857,317,919.08	233,179,190.75	21,900,610.00	26,551.81	147,272.30	1,271,280.00	305,086.40	189,152.80	647,824.30	0.00	84,324.54	16,507.52
	857,317,919.08	582,947,976.88	21,900,610.00	26,551.81	147,272.30	1,271,280.00	305,086.40	189,152.80	647,824.30	0.00	84,324.54	16,507.52
	857,317,919.08	1,165,895,953.75	21,900,610.00	26,551.81	147,272.30	1,271,280.00	305,086.40	189,152.80	647,824.30	0.00	84,324.54	16,507.52
	1,285,976,878.61	174,884,393.06	22,511,700.00	48,817.25	147,272.30	1,249,015.00	305,086.40	189,152.80	647,824.30	0.00	84,324.54	16,507.52
	1,714,635,838.15	233,179,190.75	23,014,670.00	70,909.99	147,272.30	1,224,534.00	305,086.40	189,152.80	647,824.30	0.00	84,324.54	18,895.38
	4,286,589,595.38	582,947,976.88	25,222,890.00	195,279.10	110,399.70	1,157,892.00	215,902.60	316,944.30	563,014.80	25,347.40	84,324.54	18,895.38
	8,573,179,190.75	1,165,895,953.75	25,933,650.00	405,231.00	102,931.90	962,022.50	171,553.20	334,969.80	517,623.80	87,833.60	84,324.54	21,509.58
8	**857,317,919.08**	**116,589,595.38**	**22,596,610.00**	**27,459.95**	**135,315.20**	**1,265,279.00**	**225,525.40**	**158,994.30**	**781,942.20**	**0.00**	**76,976.38**	**16,507.52**
	1,285,976,878.61	116,589,595.38	23,305,640.00	49,558.80	135,315.20	1,242,849.00	225,525.40	158,994.30	779,885.20	0.00	76,976.38	18,895.38
	1,714,635,838.15	116,589,595.38	23,904,620.00	71,590.83	135,315.20	1,216,779.00	225,525.40	165,382.30	777,535.10	0.00	76,976.38	18,895.38
	4,286,589,595.38	116,589,595.38	25,874,840.00	193,062.70	99,124.94	1,071,513.00	177,388.60	316,944.30	713,968.40	34,672.20	59,816.36	21,509.58
	8,573,179,190.75	116,589,595.38	26,437,130.00	404,015.10	99,124.94	860,172.90	165,208.30	362,791.20	627,528.00	87,833.60	59,816.36	21,509.58
	857,317,919.08	174,884,393.06	22,779,160.00	27,432.09	135,315.20	1,255,907.00	225,525.40	158,994.30	791,342.60	0.00	76,976.38	16,507.52
	857,317,919.08	233,179,190.75	22,779,160.00	27,432.09	135,315.20	1,255,907.00	225,525.40	158,994.30	791,342.60	0.00	76,976.38	16,507.52
	857,317,919.08	582,947,976.88	22,779,160.00	27,432.09	135,315.20	1,255,907.00	225,525.40	158,994.30	791,342.60	0.00	76,976.38	16,507.52
	857,317,919.08	1,165,895,953.75	22,779,160.00	27,432.09	135,315.20	1,255,907.00	225,525.40	158,994.30	791,342.60	0.00	76,976.38	16,507.52
	1,285,976,878.61	174,884,393.06	23,509,860.00	46,615.14	135,315.20	1,216,779.00	225,525.40	246,211.60	724,069.30	0.00	76,976.38	16,507.52

	1,714,635,838.15	233,179,190.75	24,116,770.00	68,975.36	133,733.50	1,216,779.00	225,525.40	246,211.60	713,968.40	0.00	66,298.78	16,507.52
	4,286,589,595.38	582,947,976.88	26,130,400.00	194,938.50	99,124.94	1,111,202.00	177,388.60	316,944.30	675,246.30	25,347.40	66,298.78	21,509.58
	8,573,179,190.75	1,165,895,953.75	26,689,770.00	406,776.50	99,124.94	895,464.20	165,208.30	352,891.10	611,522.40	75,686.60	59,816.36	21,509.58
10	**857,317,919.08**	**116,589,595.38**	**23,980,780.00**	**28,028.47**	**138,496.40**	**1,214,247.00**	**242,379.80**	**142,340.30**	**837,481.40**	**0.00**	**69,847.43**	**15,179.37**
	1,285,976,878.61	116,589,595.38	24,785,020.00	48,962.68	114,827.40	1,214,247.00	222,572.20	181,632.90	820,731.10	0.00	69,847.43	15,179.37
	1,714,635,838.15	116,589,595.38	25,449,420.00	67,958.08	114,827.40	1,141,000.00	191,379.00	263,691.30	805,531.50	0.00	86,045.96	17,567.23
	4,286,589,595.38	116,589,595.38	27,485,950.00	193,675.20	104,583.00	1,049,198.00	191,379.00	299,198.30	714,599.70	34,672.20	80,513.08	20,181.44
	8,573,179,190.75	116,589,595.38	27,921,940.00	407,262.20	112,022.60	833,440.50	191,379.00	337,290.80	647,314.90	75,686.60	63,421.93	20,181.44
	857,317,919.08	174,884,393.06	24,668,930.00	28,027.12	145,427.90	1,214,247.00	242,379.80	142,340.30	830,551.20	0.00	69,847.43	15,179.37
	857,317,919.08	233,179,190.75	24,825,560.00	28,009.49	145,427.90	1,209,635.00	242,379.80	142,340.30	833,699.10	0.00	71,328.82	15,179.37
	857,317,919.08	582,947,976.88	24,834,480.00	28,009.49	145,427.90	1,209,635.00	242,379.80	142,340.30	833,699.10	0.00	71,328.82	15,179.37
	857,317,919.08	1,165,895,953.75	24,834,480.00	28,009.49	145,427.90	1,209,635.00	242,379.80	142,340.30	833,699.10	0.00	71,328.82	15,179.37
	1,285,976,878.61	174,884,393.06	25,483,560.00	49,722.62	145,427.90	1,203,021.00	242,379.80	159,677.60	802,743.90	0.00	69,847.43	15,179.37
	1,714,635,838.15	233,179,190.75	26,339,080.00	67,011.95	145,427.90	1,049,198.00	242,379.80	291,443.90	806,030.20	0.00	71,328.82	15,179.37
	4,286,589,595.38	582,947,976.88	28,480,810.00	195,949.70	140,025.00	1,021,319.00	242,379.80	291,443.90	690,546.20	25,347.40	63,421.93	17,567.23
	8,573,179,190.75	1,165,895,953.75	28,950,390.00	408,831.40	408,831.40	811,411.60	214,111.50	291,443.90	688,084.20	75,686.60	63,421.93	20,181.44
12	**857,317,919.08**	**116,589,595.38**	**24,441,030.00**	**28,113.57**	**114,827.40**	**1,214,998.00**	**283,864.00**	**142,340.30**	**819,979.80**	**0.00**	**68,698.01**	**15,179.37**
	1,285,976,878.61	116,589,595.38	25,325,050.00	48,089.28	114,827.40	1,214,247.00	201,249.30	205,729.90	819,979.80	0.00	68,698.01	15,179.37
	1,714,635,838.15	116,589,595.38	25,999,450.00	66,968.22	114,827.40	1,117,136.00	191,379.00	291,443.90	819,979.80	0.00	68,698.01	17,567.23
	4,286,589,595.38	116,589,595.38	28,053,450.00	191,207.10	114,827.40	1,049,198.00	191,379.00	291,443.90	711,857.00	49,208.05	68,698.01	20,181.44
	8,573,179,190.75	116,589,595.38	28,383,270.00	406,591.50	114,827.40	854,321.40	191,379.00	291,443.90	652,723.80	87,833.60	68,698.01	20,181.44
	857,317,919.08	174,884,393.06	25,275,510.00	28,309.97	140,207.80	1,214,247.00	233,679.70	133,666.90	851,380.50	0.00	71,328.82	15,179.37
	857,317,919.08	233,179,190.75	25,608,740.00	27,983.62	140,207.80	1,205,900.00	233,679.70	142,340.30	851,380.50	0.00	71,328.83	15,179.37
	857,317,919.08	582,947,976.88	25,693,950.00	27,983.62	140,207.80	1,205,900.00	233,679.70	142,340.30	851,380.50	0.00	71,328.82	15,179.37
	857,317,919.08	1,165,895,953.75	25,693,950.00	27,983.62	140,207.80	1,205,900.00	233,679.70	142,340.30	851,380.50	0.00	71,328.82	15,179.37
	1,285,976,878.61	174,884,393.06	26,181,220.00	48,933.78	114,827.40	1,214,247.00	191,379.00	180,724.20	851,380.50	0.00	71,328.82	15,179.37
	1,714,635,838.15	233,179,190.75	27,208,190.00	68,128.73	140,207.80	1,049,198.00	233,679.70	258,897.00	851,380.50	0.00	71,328.82	15,179.37
	4,286,589,595.38	582,947,976.88	29,497,400.00	193,397.20	114,827.40	1,049,198.00	191,379.00	291,443.90	720,236.60	38,621.80	71,328.83	17,567.23
	8,573,179,190.75	1,165,895,953.75	29,896,390.00	398,277.00	114,827.40	740,110.30	191,379.00	291,443.90	730,760.20	129,692.00	71,328.83	20,181.44
16	**857,317,919.08**	**116,589,595.38**	**24,612,960.00**	**29,589.61**	**140,207.80**	**1,277,591.00**	**273,718.10**	**116,839.80**	**685,181.00**	**0.00**	**69,847.43**	**15,179.37**
	1,285,976,878.61	116,589,595.38	25,603,120.00	45,351.89	140,207.80	1,214,247.00	250,956.00	291,443.90	630,964.50	0.00	69,847.43	15,179.37
	1,714,635,838.15	116,589,595.38	26,329,280.00	67,369.64	128,985.20	1,214,247.00	256,721.90	291,443.90	641,817.70	0.00	69,847.43	17,567.23
	4,286,589,595.38	116,589,595.38	28,220,890.00	190,565.10	114,827.40	1,104,756.00	210,671.00	337,290.80	595,751.60	45,258.75	68,698.01	20,181.44
	8,573,179,190.75	116,589,595.38	28,570,120.00	406,020.20	114,827.40	950,660.50	191,379.00	316,944.30	542,369.10	87,833.60	57,784.40	20,181.44
	857,317,919.08	174,884,393.06	25,455,630.00	28,943.14	140,207.80	1,230,441.00	233,679.70	116,839.80	851,380.50	0.00	71,328.82	15,179.37
	857,317,919.08	233,179,190.75	25,820,030.00	28,907.44	140,207.80	1,221,994.00	233,679.70	116,839.80	855,865.70	0.00	75,326.01	15,179.37
	857,317,919.08	582,947,976.88	25,894,880.00	28,884.41	140,207.80	1,214,247.00	233,679.70	116,839.80	863,636.00	0.00	75,326.01	15,179.37
	857,317,919.08	1,165,895,953.75	25,894,880.00	28,884.41	140,207.80	1,214,247.00	233,679.70	116,839.80	863,636.00	0.00	75,326.01	15,179.37
	1,285,976,878.61	174,884,393.06	26,454,060.00	48,933.78	114,827.40	1,214,247.00	191,379.00	180,724.20	851,380.50	0.00	71,328.82	15,179.37

	1,714,635,838.15	233,179,190.75	27,522,700.00	67,004.46	114,827.40	1,060,685.00	216,150.50	291,443.90	851,380.50	0.00	71,328.82	15,179.37
	4,286,589,595.38	582,947,976.88	29,625,560.00	189,863.70	114,827.40	1,049,198.00	191,379.00	291,443.90	705,207.90	57,184.00	71,328.82	17,567.23
	8,573,179,190.75	1,165,895,953.75	30,002,330.00	398,606.10	114,827.40	850,798.10	191,379.00	291,443.90	619,743.30	129,692.00	71,328.83	20,181.44
	857,317,919.08	**116,589,595.38**	**24,613,540.00**	**29,576.44**	**140,207.80**	**1,282,775.00**	**277,087.40**	**116,839.80**	**683,087.00**	**0.00**	**69,847.43**	**15,179.37**
	1,285,976,878.61	116,589,595.38	25,608,170.00	45,251.35	140,207.80	1,214,247.00	246,531.80	291,443.90	652,678.80	0.00	69,847.43	15,179.37
	1,714,635,838.15	116,589,595.38	26,336,370.00	67,374.37	130,710.40	1,214,247.00	259,511.50	291,443.90	637,298.20	0.00	69,847.43	17,567.23
	4,286,589,595.38	116,589,595.38	28,220,890.00	190,565.10	114,827.40	1,104,756.00	210,671.00	337,290.80	595,751.60	45,258.75	68,698.01	20,181.44
	8,573,179,190.75	116,589,595.38	28,570,120.00	406,020.20	114,827.40	950,660.50	191,379.00	316,944.30	542,369.10	87,833.60	57,784.39	20,181.44
	857,317,919.08	174,884,393.06	25,455,860.00	28,943.14	140,207.80	1,230,441.00	233,679.70	116,839.80	851,380.50	0.00	71,328.83	15,179.37
20	857,317,919.08	233,179,190.75	25,820,460.00	28,896.14	140,207.80	1,218,192.00	233,679.70	116,839.80	859,679.50	0.00	75,326.01	15,179.37
	857,317,919.08	582,947,976.88	25,894,880.00	28,884.41	140,207.80	1,214,247.00	233,679.70	116,839.80	863,636.00	0.00	75,326.01	15,179.37
	857,317,919.08	1,165,895,953.75	25,894,880.00	28,884.41	140,207.80	1,214,247.00	233,679.70	116,839.80	863,636.00	0.00	75,326.01	15,179.37
	1,285,976,878.61	174,884,393.06	26,454,070.00	48,933.78	114,827.40	1,214,247.00	191,379.00	180,724.20	851,380.50	0.00	71,328.82	15,179.37
	1,714,635,838.15	233,179,190.75	27,522,770.00	67,001.74	114,827.40	1,058,336.00	218,501.80	291,443.90	851,380.50	0.00	71,328.82	15,179.37
	4,286,589,595.38	582,947,976.88	29,625,560.00	189,863.70	114,827.40	1,049,198.00	191,379.00	291,443.90	705,207.90	57,184.00	71,328.83	17,567.23
	8,573,179,190.75	1,165,895,953.75	30,002,330.00	398606.10	114827.40	850,798.10	191,379.00	291,443.90	619,743.30	129,692.00	71,328.83	20,181.44
	857,317,919.08	**116,589,595.38**	**24,613,540.00**	**29,576.44**	**140,207.80**	**1,282,775.00**	**277,087.40**	**116,839.80**	**683,087.00**	**0.00**	**69,847.43**	**15,179.37**
	1,285,976,878.61	116,589,595.38	25,608,170.00	45,251.35	140,207.80	1,214,247.00	246,531.80	291,443.90	652,678.80	0.00	69,847.43	15,179.37
	1,714,635,838.15	116,589,595.38	26,336,370.00	67,374.37	130,710.40	1,214,247.00	259,511.50	291,443.90	637,298.20	0.00	69,847.43	17,567.23
	4,286,589,595.38	116,589,595.38	28,220,890.00	190,565.10	114,827.40	1,104,756.00	210,671.00	337,290.80	595,751.60	45,258.75	68,698.01	20,181.44
	8,573,179,190.75	116,589,595.38	28,570,120.00	406,020.20	114,827.40	950,660.50	191,379.00	316,944.30	542,369.10	87,833.60	57,784.39	20,181.44
	857,317,919.08	174,884,393.06	25,455,860.00	28,943.14	140,207.80	1,230,441.00	233,679.70	116,839.80	851,380.50	0.00	71,328.82	15,179.37
22	857,317,919.08	233,179,190.75	25,820,460.00	28,896.14	140,207.80	1,218,192.00	233,679.70	116,839.80	859,679.50	0.00	75,326.01	15,179.37
	857,317,919.08	582,947,976.88	25,894,880.00	28,884.41	140,207.80	1,214,247.00	233,679.70	116,839.80	863,636.00	0.00	75,326.01	15,179.37
	857,317,919.08	1,165,895,953.75	25,894,880.00	28,884.41	140,207.80	1,214,247.00	233,679.70	116,839.80	863,636.00	0.00	75,326.01	15,179.37
	1,285,976,878.61	174,884,393.06	26,454,070.00	48,933.78	114,827.40	1,214,247.00	191,379.00	180,724.20	851,380.50	0.00	71,328.82	15,179.37
	1,714,635,838.15	233,179,190.75	27,522,770.00	67,001.74	114,827.40	1,058,336.00	218,501.80	291,443.90	851,380.50	0.00	71,328.83	15,179.37
	4,286,589,595.38	582,947,976.88	29,625,560.00	189,863.70	114,827.40	1,049,198.00	191,379.00	291,443.90	705,207.90	57,184.00	71,328.82	17,567.23
	8,573,179,190.75	1,165,895,953.75	30,002,330.00	398,606.10	114,827.40	850,798.10	191,379.00	291,443.90	619,743.30	129,692.00	71,328.82	20,181.44

G. Sensitivity analysis of total proportion

(Capacity of each distribution centre = 84,000 m³)

Resp. time (hours)	Pre-disaster budget ($)	Post-disaster budget ($)	Total expected relief demand (unit)	Total proportion of relief demand satisfied								
				Medicine A	Instant food B	Rice C	Drinking water D	Blanket E	Clothes F	Tent G	Mat H	Lantern Lamp I
7.3	**857,317,919.08**	**116,589,595.38**	**17,165,980.00**	**12.88**	**26.82**	**30.33**	**26.82**	**30.58**	**13.98**	**0.00**	**16.85**	**32.62**
	1,285,976,878.61	116,589,595.38	17,667,530.00	16.92	26.62	30.42	26.58	31.28	12.31	0.00	16.76	32.62
	1,714,635,838.15	116,589,595.38	18,062,110.00	19.36	26.79	30.16	26.84	31.28	11.87	0.00	16.73	32.62
	4,286,589,595.38	116,589,595.38	19,444,830.00	28.68	23.45	29.67	23.52	31.27	11.62	0.00	13.25	32.87
	8,573,179,190.75	116,589,595.38	19,529,000.00	30.69	23.18	29.08	22.58	31.28	10.54	0.00	12.85	32.87
	857,317,919.08	174,884,393.06	17,165,980.00	12.88	26.84	30.33	26.82	30.58	13.98	0.00	16.85	32.62
	857,317,919.08	233,179,190.75	17,165,980.00	12.88	26.82	30.33	26.83	30.58	13.98	0.00	16.85	32.62
	857,317,919.08	582,947,976.88	17,165,980.00	12.88	26.81	30.33	26.83	30.58	13.98	0.00	16.85	32.62
	857,317,919.08	1,165,895,953.75	17,165,980.00	12.88	26.81	30.33	26.83	30.58	13.98	0.00	16.85	32.62
	1,285,976,878.61	174,884,393.06	17,667,530.00	16.92	26.62	30.42	26.58	31.28	12.31	0.00	16.76	32.62
	1,714,635,838.15	233,179,190.75	18,062,110.00	19.36	26.82	30.16	26.82	31.28	11.87	0.00	16.73	32.62
	4,286,589,595.38	582,947,976.88	19,444,830.00	28.68	23.45	29.67	23.52	31.27	11.62	0.00	13.25	32.87
	8,573,179,190.75	1,165,895,953.75	19,529,000.00	30.69	22.34	29.08	23.09	31.28	10.54	0.00	12.85	32.87
8	**857,317,919.08**	**116,589,595.38**	**17,979,240.00**	**14.57**	**26.29**	**30.37**	**26.38**	**30.83**	**19.47**	**0.00**	**22.24**	**32.62**
	1,285,976,878.61	116,589,595.38	18,567,630.00	19.25	26.29	30.37	26.29	30.83	18.61	0.00	22.26	32.62
	1,714,635,838.15	116,589,595.38	19,059,470.00	21.97	26.29	30.27	26.29	31.01	17.88	0.00	22.36	32.62
	4,286,589,595.38	116,589,595.38	20,404,920.00	29.39	24.80	29.74	24.74	31.28	17.07	0.00	18.51	32.87
	8,573,179,190.75	116,589,595.38	20,441,220.00	30.29	24.95	29.42	25.25	31.28	15.05	0.00	18.51	32.87
	857,317,919.08	174,884,393.06	17,979,240.00	14.57	26.29	30.37	26.38	30.83	19.47	0.00	22.24	32.62
	857,317,919.08	233,179,190.75	17,979,240.00	14.57	26.29	30.37	26.38	30.83	19.47	0.00	22.24	32.62
	857,317,919.08	582,947,976.88	17,979,240.00	14.57	26.29	30.37	26.38	30.83	19.47	0.00	22.24	32.62
	857,317,919.08	1,165,895,953.75	17,979,240.00	14.57	26.29	30.37	26.38	30.83	19.47	0.00	22.24	32.62
	1,285,976,878.61	174,884,393.06	18,567,630.00	19.25	26.29	30.37	26.29	30.83	18.61	0.00	22.26	32.62
	1,714,635,838.15	233,179,190.75	19,059,470.00	21.97	26.29	30.27	26.29	31.01	17.88	0.00	22.36	32.62
	4,286,589,595.38	582,947,976.88	20,404,920.00	29.39	24.80	29.74	24.74	31.28	17.07	0.00	18.51	32.87
	8,573,179,190.75	1,165,895,953.75	20,441,220.00	30.29	25.19	29.42	25.11	31.28	15.05	0.00	18.51	32.87

	857,317,919.08	**116,589,595.38**	**20,015,700.00**	**16.66**	**28.38**	**31.37**	**28.94**	**31.28**	**20.41**	**0.00**	**24.17**	**32.62**
	1,285,976,878.61	116,589,595.38	20,729,620.00	21.60	28.74	31.39	28.51	31.28	19.98	0.00	21.68	32.62
	1,714,635,838.15	116,589,595.38	21,318,170.00	24.77	28.31	31.35	28.77	31.28	19.76	0.00	20.40	32.62
	4,286,589,595.38	116,589,595.38	22,786,290.00	30.48	27.83	30.84	27.86	31.68	18.56	0.00	19.00	33.00
	8,573,179,190.75	116,589,595.38	22,810,170.00	31.19	27.88	30.45	27.83	31.62	18.56	0.00	19.00	33.00
	857,317,919.08	174,884,393.06	20,021,410.00	16.66	28.71	31.37	28.74	31.28	20.42	0.00	24.17	32.62
10	857,317,919.08	233,179,190.75	20,021,410.00	16.66	28.63	31.37	28.79	31.28	20.42	0.00	24.17	32.62
	857,317,919.08	582,947,976.88	20,021,410.00	16.66	28.56	31.37	28.83	31.28	20.42	0.00	24.17	32.62
	857,317,919.08	1,165,895,953.75	20,021,410.00	16.66	28.65	31.37	28.77	31.28	20.42	0.00	24.17	32.62
	1,285,976,878.61	174,884,393.06	20,735,270.00	21.60	28.31	31.39	28.77	31.28	19.98	0.00	21.68	32.62
	1,714,635,838.15	233,179,190.75	21,323,240.00	24.77	28.31	31.35	28.77	31.28	19.77	0.00	20.40	32.62
	4,286,589,595.38	582,947,976.88	22,791,330.00	30.51	27.83	30.82	27.86	31.68	18.56	0.00	19.00	33.00
	8,573,179,190.75	1,165,895,953.75	22,814,930.00	31.19	27.83	30.45	27.86	31.62	18.56	0.00	19.00	33.00
	857,317,919.08	**116,589,595.38**	**21,136,780.00**	**17.43**	**29.50**	**31.16**	**29.50**	**31.05**	**25.05**	**0.00**	**26.06**	**31.05**
	1,285,976,878.61	116,589,595.38	21,899,580.00	22.25	29.50	31.13	29.50	31.05	24.65	0.00	26.06	32.62
	1,714,635,838.15	116,589,595.38	22,508,030.00	25.39	29.49	31.13	29.50	31.05	24.22	0.00	26.05	32.62
	4,286,589,595.38	116,589,595.38	24,078,360.00	30.75	29.49	31.05	29.32	31.25	20.64	3.84	23.79	32.87
	8,573,179,190.75	116,589,595.38	24,139,260.00	31.05	29.31	31.05	29.31	31.07	20.47	0.88	21.19	32.87
	857,317,919.08	174,884,393.06	21,309,920.00	17.53	29.50	31.05	29.50	31.05	25.69	0.00	26.29	31.05
12	857,317,919.08	233,179,190.75	21,309,920.00	17.53	29.50	31.05	29.50	31.05	25.69	0.00	26.29	31.05
	857,317,919.08	582,947,976.88	21,309,920.00	17.55	29.50	31.05	29.50	31.05	25.68	0.00	26.29	31.05
	857,317,919.08	1,165,895,953.75	21,309,920.00	17.51	29.50	31.05	29.50	31.05	25.68	0.00	26.42	31.05
	1,285,976,878.61	174,884,393.06	22,071,100.00	22.40	29.50	31.05	29.50	31.05	25.21	0.00	26.06	32.62
	1,714,635,838.15	233,179,190.75	22,684,300.00	25.55	29.50	31.05	29.50	31.05	24.81	0.00	26.06	32.62
	4,286,589,595.38	582,947,976.88	24,247,980.00	30.73	29.14	31.05	29.30	31.09	20.88	8.81	24.48	32.87
	8,573,179,190.75	1,165,895,953.75	24,303,170.00	31.05	29.32	31.05	29.32	31.09	20.65	0.16	21.08	32.87
	857,317,919.08	**116,589,595.38**	**21,577,260.00**	**18.07**	**29.66**	**31.16**	**29.66**	**31.05**	**25.83**	**0.00**	**26.84**	**31.05**
	1,285,976,878.61	116,589,595.38	22,407,190.00	23.25	29.66	31.14	29.66	31.05	25.36	0.00	26.84	32.62
	1,714,635,838.15	116,589,595.38	23,017,220.00	26.39	29.66	31.11	29.66	31.05	25.06	0.00	26.83	32.62
	4,286,589,595.38	116,589,595.38	24,412,670.00	30.73	29.58	31.05	29.63	31.05	21.77	8.97	25.55	32.87
	8,573,179,190.75	116,589,595.38	24,482,810.00	31.05	29.47	31.05	29.41	31.05	21.67	2.06	23.33	32.87
16	857,317,919.08	174,884,393.06	21,938,120.00	18.04	29.66	31.05	29.69	31.05	26.95	0.00	27.06	31.05
	857,317,919.08	233,179,190.75	22,054,990.00	18.04	29.66	31.05	29.71	31.05	27.05	0.00	27.06	31.05
	857,317,919.08	582,947,976.88	22,054,990.00	18.04	29.66	31.05	29.71	31.05	27.05	0.00	27.06	31.05
	857,317,919.08	1,165,895,953.75	22,054,990.00	18.04	29.66	31.05	29.71	31.05	27.05	0.00	27.06	31.05
	1,285,976,878.61	174,884,393.06	22,782,020.00	23.34	29.66	31.05	29.66	31.05	26.60	0.00	27.05	31.05
	1,714,635,838.15	233,179,190.75	23,510,080.00	26.45	29.66	31.05	29.66	31.05	26.30	0.00	27.05	31.05
	4,286,589,595.38	582,947,976.88	24,838,930.00	30.78	29.66	31.05	29.66	31.05	23.22	0.00	25.85	31.05

	8,573,179,190.75	1,165,895,953.75	24,893,100.00	31.05	29.37	31.05	29.56	31.05	22.76	0.00	22.76	31.05
	857,317,919.08	**116,589,595.38**	**21,577,260.00**	**18.07**	**29.66**	**31.16**	**29.66**	**31.05**	**25.83**	**0.00**	**26.84**	**31.05**
	1,285,976,878.61	116,589,595.38	22,407,190.00	23.25	29.66	31.14	29.66	31.05	25.36	0.00	26.84	32.62
	1,714,635,838.15	116,589,595.38	23,017,220.00	26.39	29.66	31.11	29.66	31.05	25.06	0.00	26.83	32.62
	4,286,589,595.38	116,589,595.38	24,413,010.00	30.73	29.66	31.05	29.59	31.05	21.77	8.97	25.55	32.87
	8,573,179,190.75	116,589,595.38	24,485,250.00	31.05	29.47	31.05	29.42	31.05	21.67	2.26	23.12	32.87
	857,317,919.08	174,884,393.06	21,953,400.00	18.04	29.66	31.05	29.71	31.05	26.96	0.00	27.06	31.05
20	857,317,919.08	233,179,190.75	22,054,990.00	18.04	29.66	31.05	29.71	31.05	27.05	0.00	27.06	31.05
	857,317,919.08	582,947,976.88	22,054,990.00	18.04	29.66	31.05	29.71	31.05	27.05	0.00	27.06	31.05
	857,317,919.08	1,165,895,953.75	22,054,990.00	18.04	29.66	31.05	29.71	31.05	27.05	0.00	27.06	31.05
	1,285,976,878.61	174,884,393.06	22,797,610.00	23.34	29.66	31.05	29.66	31.05	26.61	0.00	27.05	31.05
	1,714,635,838.15	233,179,190.75	23,510,080.00	26.45	29.66	31.05	29.66	31.05	26.30	0.00	27.05	31.05
	4,286,589,595.38	582,947,976.88	24,838,930.00	30.78	29.66	31.05	29.66	31.05	23.22	0.00	25.85	31.05
	8,573,179,190.75	1,165,895,953.75	24,893,100.00	31.05	29.56	31.05	29.45	31.05	22.76	0.00	22.76	31.05
	857,317,919.08	**116,589,595.38**	**21,577,260.00**	**18.07**	**29.66**	**31.16**	**29.66**	**31.05**	**25.83**	**0.00**	**26.84**	**31.05**
	1,285,976,878.61	116,589,595.38	22,407,190.00	23.25	29.66	31.14	29.66	31.05	25.36	0.00	26.84	32.62
	1,714,635,838.15	116,589,595.38	23,017,220.00	26.39	29.66	31.11	29.66	31.05	25.06	0.00	26.83	32.62
	4,286,589,595.38	116,589,595.38	24,413,010.00	30.73	29.65	31.05	29.59	31.05	21.77	8.97	25.55	32.87
	8,573,179,190.75	116,589,595.38	24,485,250.00	31.05	29.56	31.05	29.36	31.05	21.67	2.26	23.12	32.87
	857,317,919.08	174,884,393.06	21,953,400.00	18.04	29.66	31.05	29.71	31.05	26.96	0.00	27.06	31.05
22	857,317,919.08	233,179,190.75	22,054,990.00	18.04	29.66	31.05	29.71	31.05	27.05	0.00	27.06	31.05
	857,317,919.08	582,947,976.88	22,054,990.00	18.04	29.66	31.05	29.71	31.05	27.05	0.00	27.06	31.05
	857,317,919.08	1,165,895,953.75	22,054,990.00	18.04	29.66	31.05	29.71	31.05	27.05	0.00	27.06	31.05
	1,285,976,878.61	174,884,393.06	22,797,620.00	23.34	29.66	31.05	29.66	31.05	26.61	0.00	27.05	31.05
	1,714,635,838.15	233,179,190.75	23,510,080.00	26.45	29.66	31.05	29.66	31.05	26.30	0.00	27.05	31.05
	4,286,589,595.38	582,947,976.88	24,838,930.00	30.78	29.66	31.05	29.66	31.05	23.22	0.00	25.85	31.05
	8,573,179,190.75	1,165,895,953.75	24,893,100.00	31.05	29.56	31.05	29.45	31.05	22.76	0.00	22.76	31.05

(Capacity of each distribution centre = 84,000 m³)

Response time (hours)	Pre-disaster budget ($)	Post-disaster budget ($)	Total expected relief demand (unit)	Total proportion of relief demand satisfied								
				Medicine A	Instant food B	Rice C	Drinking water D	Blanket E	Clothes F	Tent G	Mat H	Lantern Lamp I
7.3	**857,317,919.08**	**116,589,595.38**	**21,866,000.00**	**10.93**	**30.00**	**32.56**	**30.14**	**31.47**	**22.77**	**0.00**	**26.66**	**32.62**
	1,285,976,878.61	116,589,595.38	22,481,760.00	16.16	30.03	32.54	30.14	31.47	22.55	0.00	26.66	32.62
	1,714,635,838.15	116,589,595.38	22,990,040.00	18.87	30.06	32.51	30.19	31.57	22.22	0.00	26.72	32.87
	4,286,589,595.38	116,589,595.38	25,200,570.00	27.87	27.81	32.28	28.38	32.62	21.39	5.97	26.73	32.87
	8,573,179,190.75	116,589,595.38	25,910,540.00	31.51	27.23	31.72	27.23	32.62	21.83	12.62	26.75	33.00
	857,317,919.08	174,884,393.06	21,900,610.00	10.96	29.00	32.59	30.10	31.47	23.10	0.00	26.77	32.62
	857,317,919.08	233,179,190.75	21,900,610.00	10.96	28.94	32.59	30.13	31.47	23.10	0.00	26.77	32.62
	857,317,919.08	582,947,976.88	21,900,610.00	10.96	28.94	32.59	30.13	31.47	23.10	0.00	26.77	32.62
	857,317,919.08	1,165,895,953.75	21,900,610.00	10.96	29.09	32.59	30.04	31.47	23.10	0.00	26.77	32.62
	1,285,976,878.61	174,884,393.06	22,511,700.00	16.17	28.94	32.57	30.13	31.47	22.89	0.00	26.77	32.62
	1,714,635,838.15	233,179,190.75	23,014,670.00	18.92	28.97	32.55	30.17	31.47	22.66	0.00	26.77	32.87
	4,286,589,595.38	582,947,976.88	25,222,890.00	27.87	27.88	32.28	28.34	32.62	21.43	5.97	26.75	32.87
	8,573,179,190.75	1,165,895,953.75	25,933,650.00	31.51	27.23	31.72	27.23	32.67	21.77	12.65	26.77	33.00
8	**857,317,919.08**	**116,589,595.38**	**22,596,610.00**	**12.80**	**29.78**	**32.63**	**29.77**	**31.20**	**25.75**	**0.00**	**27.26**	**32.62**
	1,285,976,878.61	116,589,595.38	23,305,640.00	18.11	29.86	32.60	29.69	31.20	25.72	0.00	27.24	32.87
	1,714,635,838.15	116,589,595.38	23,904,620.00	21.30	29.67	32.56	29.71	31.26	25.68	0.00	27.24	32.87
	4,286,589,595.38	116,589,595.38	25,874,840.00	28.77	28.05	32.29	28.40	32.62	25.07	8.03	25.77	33.00
	8,573,179,190.75	116,589,595.38	26,437,130.00	31.50	27.87	31.50	27.88	32.87	24.54	13.28	25.77	33.00
	857,317,919.08	174,884,393.06	22,779,160.00	12.79	29.71	32.62	29.92	31.20	26.11	0.00	27.51	32.62
	857,317,919.08	233,179,190.75	22,779,160.00	12.79	29.84	32.62	29.84	31.20	26.11	0.00	27.51	32.62
	857,317,919.08	582,947,976.88	22,779,160.00	12.79	29.96	32.62	29.77	31.20	26.11	0.00	27.51	32.62
	857,317,919.08	1,165,895,953.75	22,779,160.00	12.79	29.85	32.62	29.84	31.20	26.11	0.00	27.51	32.62
	1,285,976,878.61	174,884,393.06	23,509,860.00	17.63	29.73	32.56	29.96	31.98	25.52	0.00	27.50	32.62
	1,714,635,838.15	233,179,190.75	24,116,770.00	21.03	29.69	32.56	29.90	31.98	25.43	0.00	26.60	32.62
	4,286,589,595.38	582,947,976.88	26,130,400.00	28.82	28.29	32.39	28.61	32.62	24.71	6.16	26.45	33.00
	8,573,179,190.75	1,165,895,953.75	26,689,770.00	31.51	28.04	31.67	28.04	32.71	24.41	12.62	25.68	33.00
10	**857,317,919.08**	**116,589,595.38**	**23,980,780.00**	**15.00**	**30.47**	**32.80**	**30.49**	**31.28**	**27.52**	**0.00**	**27.51**	**32.62**
	1,285,976,878.61	116,589,595.38	24,785,020.00	20.20	30.29	32.79	30.40	31.63	27.20	0.00	27.78	32.62

	1,714,635,838.15	116,589,595.38	25,449,420.00	23.46	30.24	32.69	30.27	32.36	26.88	0.00	28.41	32.87
	4,286,589,595.38	116,589,595.38	27,485,950.00	29.79	29.53	32.55	29.67	32.66	26.24	11.42	28.08	33.00
	8,573,179,190.75	116,589,595.38	27,921,940.00	31.72	29.05	32.01	29.10	32.87	25.84	17.84	26.86	33.00
	857,317,919.08	174,884,393.06	24,668,930.00	15.00	30.84	32.81	30.84	31.28	28.23	0.00	28.73	32.62
	857,317,919.08	233,179,190.75	24,825,560.00	15.00	30.84	32.80	30.84	31.28	28.41	0.00	29.23	32.62
	857,317,919.08	582,947,976.88	24,834,480.00	15.00	30.84	32.80	30.84	31.28	28.43	0.00	29.04	32.62
	857,317,919.08	1,165,895,953.75	24,834,480.00	15.00	30.84	32.80	30.84	31.28	28.43	0.00	29.08	32.62
	1,285,976,878.61	174,884,393.06	25,483,560.00	20.52	30.84	32.79	30.84	31.43	27.98	0.00	28.71	32.62
	1,714,635,838.15	233,179,190.75	26,339,080.00	23.50	30.84	32.55	30.84	32.62	28.11	0.00	29.23	32.62
	4,286,589,595.38	582,947,976.88	28,480,810.00	30.40	30.77	32.48	30.84	32.62	27.03	8.83	28.39	32.87
	8,573,179,190.75	1,165,895,953.75	28,950,390.00	31.68	30.46	31.96	30.63	32.62	26.98	19.00	28.35	33.00
12	**857,317,919.08**	**116,589,595.38**	**24,441,030.00**	**15.42**	**30.60**	**32.87**	**30.92**	**31.28**	**27.86**	**0.00**	**28.66**	**32.62**
	1,285,976,878.61	116,589,595.38	25,325,050.00	20.75	30.60	32.86	30.63	31.85	27.57	0.00	28.71	32.62
	1,714,635,838.15	116,589,595.38	25,999,450.00	24.05	30.56	32.72	30.55	32.62	27.47	0.00	28.71	32.87
	4,286,589,595.38	116,589,595.38	28,053,450.00	30.55	30.11	32.62	30.35	32.62	26.66	14.73	28.06	33.00
	8,573,179,190.75	116,589,595.38	28,383,270.00	31.74	30.01	32.13	29.98	32.62	26.46	19.32	28.06	33.00
	857,317,919.08	174,884,393.06	25,275,510.00	15.50	31.05	32.87	31.05	31.20	28.99	0.00	29.63	32.62
	857,317,919.08	233,179,190.75	25,608,740.00	15.37	31.05	32.86	31.05	31.28	29.52	0.00	29.64	32.62
	857,317,919.08	582,947,976.88	25,693,950.00	15.37	31.05	32.86	31.05	31.28	29.57	0.00	29.66	32.62
	857,317,919.08	1,165,895,953.75	25,693,950.00	15.37	31.05	32.86	31.05	31.28	29.59	0.00	29.66	32.62
	1,285,976,878.61	174,884,393.06	26,181,220.00	20.92	30.68	32.87	30.68	31.62	29.01	0.00	29.63	32.62
	1,714,635,838.15	233,179,190.75	27,208,190.00	24.21	31.05	32.62	31.05	32.32	29.42	0.00	29.63	32.62
	4,286,589,595.38	582,947,976.88	29,497,400.00	30.58	30.68	32.62	30.68	32.62	28.46	13.05	29.66	32.87
	8,573,179,190.75	1,165,895,953.75	29,896,390.00	31.71	30.68	31.85	30.68	32.62	28.59	24.85	29.66	33.00
16	**857,317,919.08**	**116,589,595.38**	**24,612,960.00**	**16.50**	**30.79**	**32.92**	**30.91**	**31.05**	**27.61**	**0.00**	**29.02**	**32.62**
	1,285,976,878.61	116,589,595.38	25,603,120.00	21.04	30.67	32.82	30.80	32.62	27.29	0.00	28.74	32.62
	1,714,635,838.15	116,589,595.38	26,329,280.00	25.11	30.64	32.80	30.67	32.62	27.28	0.00	28.73	32.87
	4,286,589,595.38	116,589,595.38	28,220,890.00	30.54	30.06	32.66	30.20	32.87	26.72	13.53	28.58	33.00
	8,573,179,190.75	116,589,595.38	28,570,120.00	31.74	29.96	32.33	29.90	32.76	26.37	18.83	27.88	33.00
	857,317,919.08	174,884,393.06	25,455,630.00	16.27	31.05	32.88	31.05	31.05	29.19	0.00	29.66	32.62
	857,317,919.08	233,179,190.75	25,820,030.00	16.26	31.05	32.88	31.05	31.05	29.61	0.00	29.86	32.62
	857,317,919.08	582,947,976.88	25,894,880.00	16.25	31.05	32.87	31.05	31.05	29.71	0.00	29.86	32.62
	857,317,919.08	1,165,895,953.75	25,894,880.00	16.25	31.05	32.87	31.05	31.05	29.71	0.00	29.86	32.62
	1,285,976,878.61	174,884,393.06	26,454,060.00	21.83	30.68	32.87	30.68	31.62	29.22	0.00	29.66	32.62
	1,714,635,838.15	233,179,190.75	27,522,700.00	25.06	30.68	32.63	30.90	32.62	29.57	0.00	29.66	32.62
	4,286,589,595.38	582,947,976.88	29,625,560.00	30.53	30.68	32.62	30.68	32.62	28.70	17.47	29.66	32.87

	8,573,179,190.75	1,165,895,953.75	30,002,330.00	31.71	30.68	32.12	30.68	32.62	28.13	25.85	29.66	33.00
	857,317,919.08	**116,589,595.38**	**24,613,540.00**	**16.50**	**30.79**	**32.92**	**30.91**	**31.05**	**27.59**	**0.00**	**29.05**	**32.62**
	1,285,976,878.61	116,589,595.38	25,608,170.00	21.02	30.75	32.82	30.75	32.62	27.34	0.00	28.74	32.62
	1,714,635,838.15	116,589,595.38	26,336,370.00	25.11	30.67	32.82	30.66	32.62	27.21	0.00	28.73	32.87
	4,286,589,595.38	116,589,595.38	28,220,890.00	30.54	30.17	32.66	30.14	32.87	26.72	13.53	28.58	33.00
	8,573,179,190.75	116,589,595.38	28,570,120.00	31.74	29.99	32.33	29.89	32.76	26.37	18.83	27.88	33.00
	857,317,919.08	174,884,393.06	25,455,860.00	16.27	31.05	32.88	31.05	31.05	29.20	0.00	29.66	32.62
20	857,317,919.08	233,179,190.75	25,820,460.00	16.25	31.05	32.87	31.05	31.05	29.63	0.00	29.86	32.62
	857,317,919.08	582,947,976.88	25,894,880.00	16.25	31.05	32.87	31.05	31.05	29.71	0.00	29.86	32.62
	857,317,919.08	1,165,895,953.75	25,894,880.00	16.25	31.05	32.87	31.05	31.05	29.71	0.00	29.86	32.62
	1,285,976,878.61	174,884,393.06	26,454,070.00	21.83	30.68	32.87	30.68	31.62	29.22	0.00	29.66	32.62
	1,714,635,838.15	233,179,190.75	27,522,770.00	25.06	30.68	32.63	30.92	32.62	29.57	0.00	29.66	32.62
	4,286,589,595.38	582,947,976.88	29,625,560.00	30.53	30.68	32.62	30.68	32.62	28.70	17.47	29.66	32.87
	8,573,179,190.75	1,165,895,953.75	30,002,330.00	31.71	30.68	32.12	30.68	32.62	28.13	25.85	29.66	33.00
	857,317,919.08	**116,589,595.38**	**24,613,540.00**	**16.50**	**30.79**	**32.92**	**30.91**	**31.05**	**27.59**	**0.00**	**29.05**	**32.62**
	1,285,976,878.61	116,589,595.38	25,608,170.00	21.02	30.79	32.82	30.72	32.62	27.34	0.00	28.74	32.62
	1,714,635,838.15	116,589,595.38	26,336,370.00	25.11	30.67	32.82	30.66	32.62	27.21	0.00	28.73	32.87
	4,286,589,595.38	116,589,595.38	28,220,890.00	30.54	30.16	32.66	30.14	32.87	26.72	13.53	28.58	33.00
	8,573,179,190.75	116,589,595.38	28,570,120.00	31.74	30.07	32.33	29.83	32.76	26.37	18.83	27.88	33.00
	857,317,919.08	174,884,393.06	25,455,860.00	16.27	31.05	32.88	31.05	31.05	29.20	0.00	29.66	32.62
22	857,317,919.08	233,179,190.75	25,820,460.00	16.25	31.05	32.87	31.05	31.05	29.63	0.00	29.86	32.62
	857,317,919.08	582,947,976.88	25,894,880.00	16.25	31.05	32.87	31.05	31.05	29.71	0.00	29.86	32.62
	857,317,919.08	1,165,895,953.75	25,894,880.00	16.25	31.05	32.87	31.05	31.05	29.71	0.00	29.86	32.62
	1,285,976,878.61	174,884,393.06	26,454,070.00	21.83	30.68	32.87	30.68	31.62	29.22	0.00	29.66	32.62
	1,714,635,838.15	233,179,190.75	27,522,770.00	25.06	30.68	32.63	30.92	32.62	29.57	0.00	29.66	32.62
	4,286,589,595.38	582,947,976.88	29,625,560.00	30.53	30.68	32.62	30.68	32.62	28.70	17.47	29.66	32.87
	8,573,179,190.75	1,165,895,953.75	30,002,330.00	31.71	30.68	32.12	30.68	32.62	28.13	25.85	29.66	33.00

H. LINGO Formulation

```
SETS:

!33 Disaster Area;
DISAREA/ACEH, NORTH_SUM, RIAU, WEST_SUM, JAMBI, RIAU_ISL, BANGKA_BEL, BENGKULU, SOUTH_SUM, LAMPUNG, BANTEN, JAKARTA, WEST_JAVA,
CENTRAL_JAVA, YOGYAKARTA, EAST_JAVA, BALI, WEST_NUSA_TENG, EAST_NUSA_TENG, WEST_KAL, CENTRAL_KAL, SOUTH_KAL, EAST_KAL, WEST_SUL,
SOUTH_SUL, SOUTH_EAST_SUL, CENTRAL_SUL, GORONTALO, NORTH_SUL, NORTH_MAL, MALUKU, WEST_PAPUA, PAPUA/: P, R, LIM;

!16 Distribution Centre;
DISCENTRE/BANDA_ACEH, MEDAN, TANJ_PINANG, PALEMBANG, BDR_LAMPUNG, SERANG, YOGYAKARTA, SURABAYA, MATARAM, MAKASSAR, KUPANG,
PALANGKARAYA, SAMARINDA, PALU, GORONTALO, AMBON/: CAP;

!Potential distribution center to serve disaster area with one existing distribution centre;
EDC(DISAREA, DISCENTRE): X;
!Response time constraints;
TIME(DISAREA,DISCENTRE): T, a;

!Types of products;
PRODTYPE/A,B,C,D,E,F,G,H,I/:VOL, W, Q, FT;

!Proportion of demand, Shipping cost, Quantity, Acquiring cost, and demand;
COMB1(DISAREA, DISCENTRE, PRODTYPE): f, C;
COMB2(DISCENTRE, PRODTYPE): Q_JK, G;
COMB3(DISAREA, PRODTYPE): d, FJ;

ENDSETS
DATA:

!Pre-disaster budget;
B0 = 857317919.075;
!Post-disaster budget;
B1 = 116589595.375;
```

```
!Max response time limit;
R =  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8;

!Capacity of each distribution center;
CAP = 84000, 84000, 84000, 84000, 84000, 84000, 84000, 84000, 84000, 84000, 84000, 84000, 84000, 84000, 84000, 84000;

!Volume of each item type;
VOL = 0.01887, 0.054, 0.02, 0.054, 0.009, 0.1119, 0.2, 0.05625, 0.005625;

!Criticality weight of each item type;
W = 0.13, 0.13, 0.13, 0.13, 0.07, 0.13, 0.13, 0.07, 0.07;

……………………………………………………………………………………………………. the rest of the data

END DATA

!Objective function;
!maximizes the total expected relief demand covered by the existing distribution centers;
MAX =      @SUM(COMB1(I,J,K): P(I) * d(I,K) * W(K) * f(I,J,K));

!subject to;

!ensures the inventory level at a single distribution center is no smaller than the maximum amount of demand;
@FOR (COMB1(I,J,K):
            d(I,K) * f(I,J,K) < Q_JK(J,K));

!guarantees that the amount of inventory kept at any distribution center does not exceed its capacity;
@FOR(DISCENTRE(J):
            @SUM(PRODTYPE(K): VOL(K) * Q_JK(J,K)) < CAP(J));

!requires that the preparedness expenditures related to provision of logistics for basic needs in emergency
does not exceed the pre-disaster budget;
@SUM(PRODTYPE(K):
            @SUM(DISCENTRE(J):
                        Q_JK(J,K) * G(J,K))) < B0;
```

```
!requires that the transportation costs to mobilize resources are less than the expected post-disaster budget;
@FOR(DISAREA(I):
        @SUM(DISCENTRE(J):
                @SUM(PRODTYPE(K):
                        d(I,K) * C(I,J,K) * f(I,J,K))) < B1);

!ensures the amount of supplies sent to satisfy relief demand in specific disaster area does not exceed the actual demand;
@FOR(DISAREA(I):
        @FOR(PRODTYPE(K):
                @SUM(DISCENTRE(J):
                        f(I,J,K)) <  1));


!non-negativity constraint on the proportion of demand satisfied;
@FOR (COMB1(I,J,K):
        f(I,J,K) > 0);

!ensures the amount of supplies sent to satisfy relief demand only exist when the distribution center provides service in
designated disaster areas;
@FOR (DISAREA(I):
        @FOR(DISCENTRE(J):
                @SUM(PRODTYPE(K):
                        f(I,J,K)) < 50000*X(I,J)));


!guarantees that the existing distribution center can only provide service in specific disaster area if the expected time
to satisfy relief demand is no bigger than the maximum response time limit;
@FOR (TIME(I,J):
        T(I,J) * a(I,J) < R(I));

!guarantees that a distribution center will not provide service in specific disaster area if the expected time
to satisfy relief demand is bigger than the maximum response time limit;
@FOR (TIME(I,J):
        a(I,J) > X(I,J));
```

```
!assures that there is at least one distribution center will provide service in any disaster area;
@FOR (DISAREA(I):
        @SUM(DISCENTRE(J): X(I,J)) > LIM(I));

!binary variable of potential service area;
@FOR (EDC(I,J): @BIN(X(I,J)));

!binary variable of potential response time;
@FOR (TIME(I,J): @BIN(a(I,J)));
```


PUKYONG NATIONAL UNIVERSITY
부경대학교