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Kusumastuti, Ratih Dyah and Wibowo, Sigit Sulistiyo and Insanita, Rizqiah

Fakultas Ekonomi Universitas Indonesia

7 December 2010

Online at https://mpra.ub.uni-muenchen.de/41089/
MPRA Paper No. 41089, posted 07 Sep 2012 15:53 UTC

Hierarchical Modeling Approach for Relief Logistics Nework Design

Ratih Dyah Kusumastuti †1 and Sigit Sulistiyo Wibowo[2]
Departement of Management, Faculty of Economics and Business, University of Indonesia
Kampus UI Depok 16424, Indonesia
Email: ratih.dyah@ui.ac.id[1]
sigit.sw@ui.ac.id[2]

Rizqiah Insanita
Management Institute, Faculty of Economics and Business, University of Indonesia
Jalan Salemba Raya No. 4 Jakarta, Indonesia
Email: rinsanita@lm.feui.org

Abstract – *Indonesia has been stricken by so many disasters in the last decade. To name a few of the major disasters that happened in Indonesia are the Tsunami in Aceh in 2004, earthquake in Yogyakarta in 2006 and the recent earthquakes in southern Java and Western Sumatra provinces in 2009. One of the critical success factors in successful disaster management is effective logistics management. The objective of relief (humanitarian) logistics is to rapidly provide the appropriate emergency supplies to people affected by the disasters and to minimize human suffering and death. Logistics is also very important because it accounts for eighty percent of relief operations. This research is concerned with the development of hierarchical models to design relief logistics network for a country as geographically disperse as Indonesia archipelago. The modeling approach consists of two stages, namely pre-disaster and post-disaster stages, and developed according to Indonesia's administration structure. This paper focuses on modeling for the response stage, which consists of a multi-period maximal covering location problem (MCLP) model to determine distribution points at the affected areas (village level facility), and a facility location-allocation model to decide the facility locations at the district level. The model is applied to analyze relief logistics network during the flood in Jakarta in the year of 2007.*

Keywords: *humanitarian logistics, relief logistics, disaster management*

1. INTRODUCTION

Most provinces in Indonesia are prone to natural disasters, especially earthquake, because the country is located at the meeting point of three tectonic layers, namely the Australian layer in the southern part, the Euro-Asia layer in the western part and the Pacific Ocean layer in the eastern parts (Rachmat, 2006).

The term of disaster management became popular after the Aceh Tsunami in 2004. The United Nations International Strategy for Disaster Reduction defined disaster as a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources (UN/ISDR, 2009). Disaster is often categorized based on its cause, which are natural disasters (e.g. tsunami, earthquake and volcano eruptions) and technological disasters (e.g. industrial and transport accidents). Disaster management involves plans, structures, and arrangements established to engage the normal endeavors of governments, voluntary and private agencies in a comprehensive and coordinated way to respond to the whole spectrum of emergency needs (Moe and Pathranakul, 2006).

The disaster management cycle consists of four stages, namely mitigation, preparedness, response and rehabilitation (Tomasini and van Wassenhove, 2009). Mitigation addresses the proactive social component of emergencies. Preparedness means putting in place the response mechanisms to counter factors that society has not been able to mitigate. Response includes the provision of assistance or intervention during or immediately after a disaster to meet the life preservation and basic subsistence needs of those people affected. Rehabilitation includes decisions and actions taken after a disaster with a view to restoring or improving the pre-disaster living conditions of the stricken community, while encouraging and facilitating

† : Corresponding Author

necessary adjustments to reduce disaster risk.

One of the critical success factors in successful disaster management is effective logistics management (Moe and Pathranakul, 2006). The objective of relief (humanitarian) logistics is to rapidly provide the appropriate emergency supplies to people affected by the disasters to minimize human suffering and death (Balcik et al., 2008). Logistics is also very important because it accounts for eighty percent of relief operations (van Wassenhove, 2006).

The purpose of this study to develop a modeling approach to design relief logistics network during the response stage of disaster management cycles that are suitable for geographically dispersed countries like Indonesia. The rest of this paper is organized as follows: Section 2 provides relevant literature pertaining to relief logistics. Section 3 describes briefly our observation of disaster management and relief logistics in Indonesia, based on the interview with personnel from various organizations that are usually involved in disaster management and by using secondary data and relevant publications. Section 4 describes the proposed modeling approach to design relief logistics network during response stage. Section 5 presents the case study to apply the modeling approach, and lastly, conclusions is presented in Section 6.

2. RELEVANT LITERATURE

The basic task of a logistics system is to deliver appropriate supplies, in good condition, in the quantity required, and at the places and time they are needed (Bowersox et al, 2007). Relief logistics is mostly concerned with movement of goods and equipment, but it also encompasses the relocation of disaster-affected people, transfer of casualties and the movement of relief workers (Stephenson, 1993).

Relief logistics have several unique characteristics that differentiate it from commercial logistics (Tomasini and van Wassenhove, 2009): It has ambiguous objectives (it involves a lot of parties, and it is difficult to assess the level of commitment of each party and their relationship to each other), it involves limited resources (human, capital and infrastructure), it has high degree of uncertainty and urgency, and it operates in a politicized environment. The ultimate goal of relief logistics is to deliver relief supplies in the shortest amount of time possible (or speed is the main driver).

Because a lot of parties involved in the relief logistics operations, coordinating the activities have certain challenges. Factors that affect coordination in relief logistics include the number and diversity of actors, donor expectation and funding structure, competition for funding and the effects of media, unpredictability, resource scarcity/oversupply, and the cost of coordination (Balcik et al., 2009).

The performance of relief logistics operations can be measured according three metric types (Beamon and Balcik, 2008), namely resources (the goal is high level of efficiency), output (the goal is high level of effectiveness) and flexibility (the goal is to be able to respond to a changing environment).

In the disaster management, relief logistics are involved in the preparedness and response stages (Tomasini and Wassenhove, 2009). The pre-disaster relief chain (preparedness stage) includes procurement and stock prepositioning while the post-disaster operations (response stage) focus primarily on procurement and transportation.

Other literature in relief logistics focused on developing models for operations activities, such as Church and ReVelle (1974), Adenso-Diaz & Rodriguez (1997), Kongsomsaksakul et al. (2005), Chang et al. (2007), Balcik and Beamon (2008), Balcik et al. (2008), and Rajagopalan and Seydam (2009).

3. DISASTER MANAGEMENT AND RELIEF LOGISTICS IN INDONESIA

There are four levels of government administration structure in Indonesia, namely province, district (*kabupaten*/*kotamadya*), sub-district (*kecamatan*) and village (*kelurahan/desa*). Most organizations in Indonesia follow the government structure with larger-size organizations having representatives at the provincial and district levels.

The National Agency for Disaster Management (BNPB) was founded in 2007. The agency has two functions, firstly as the policy maker of disaster management in Indonesia, and secondly as the main operation coordinator in the event of major disasters in the country, from response to rehabilitation stages (Presidential Decree No. 8 Year 2008). The agency has subsidiaries at the provincial and district levels (BPBD), and currently 20 agencies are established at the provincial level whereas 44 agencies are established at the district level (BNPB, 2010a). BNPB also planned to establish 12 technical operational units (UPT) at the regional level to support the local authorities in responding to a disaster, especially for coordination and relief logistics management (BNPB, 2008).

Government ministries are also involved in the disaster management cycle. Ministry of Health manages the health aspects of a disaster, the Ministry of Social Welfare, involves in allocating relief supplies to the affected people, whereas the Ministry of Public Works involves in clearing the affected area and also in rehabilitating the infrastructure. The abovementioned government ministries have working units in the provincial and district levels.

The Indonesia Red Cross (PMI) and several Non-Governmental Organizations (NGOs) focusing on social and welfare (including disaster management) are also involved in the disaster management cycle in Indonesia. PMI's branches are established in all of the provinces and in most districts, whereas larger-size NGOs usually have representatives at the provincial level. Foreign governments and foreign NGOs are sometimes involved too, especially in the event of a major disaster. Foreign NGOs can form partnership with local NGOs or operate on their own.

In general, in responding to a disaster, the abovementioned organizations use the almost similar standard operation procedures. Whenever a disaster strikes, several small working units will be sent to the affected areas to do rapid assessments on the disaster impacts. The report will mainly contain data, such as:

- The affected areas
- Number of casualties (number of death and injured people) and replaced people (refugees)
- Damaged houses and buildings
- Damaged infrastructures (transportation and communication)

The initial data is then used by each organization to determine the appropriate response, including the quantity of relief logistics supplies for each affected area in the early days. Detailed assessment to determine appropriate response in the long-tem is usually conducted later.

For larger-scale disaster, in the early days, all organizations (local and foreign) are usually trying to reach the affected areas at the same time. Therefore in some cases, overwhelming the local government and BPBD, and making the coordination very difficult. Coordination between all organizations involved in the response stage can only be done when the situation is settling down. This condition often leads to the uneven distribution of relief supplies in the affected areas, especially in the early days.

Concerning the relief logistics network structure, most organizations, especially larger-size organizations such as government ministries and PMI have their own relief logistics networks, which consist of permanent and temporary facilities. Permanent facilities are set up at the national/regional, provincial, and district levels, while temporary facilities are set up at the affected areas during the response stage of the disaster management cycle

Regarding the temporary relief logistics facilities at the affected area, the criteria used by the abovementioned organizations to determine the locations are listed below:

- Distance to the affected area
- Distance to the refugee shelters
- Easy access to/from locations
- Whether they are located at the disaster-safe zone
- Capacity of the potential facilities
- Security issues in the area

In setting-up the temporary relief facilities, minimizing costs has never been considered as the objective function as quickly delivery of the relief items is the main concern in order to minimize the disaster impacts on the affected people. Budget is considered more as constraint in the relief operation.

In practice, temporary facilities are usually set up based on the judgment of the local authorities. Although in the event of a disaster, locations of temporary facilities must be determined promptly, basing the decision solely on the judgment of local authorities may not result in an optimal relief logistics network structure that can lead to undersupply/oversupply of relief goods at the affected area.

4. MODELING APPROACH

In this research, the proposed relief logistics network is depicted in Figure 1. It involves two stages in the disaster management cycle, namely preparedness and response stages. To be able to quickly respond to a disaster, the proposed relief logistics network for countries that are geographically dispersed as Indonesia, consist of four echelons according to government administration levels, namely national, provincial, district and village levels facilities. Logistics facilities (i.e. warehouse) for the national and provincial levels are proposed to be permanent, whereas facilities for the district and village levels are set up when the disaster occurs. By having permanent facilities at the national and provincial levels, the response time to a disaster will be shorter, which is the travelling time between provincial and village level facilities at the affected area.

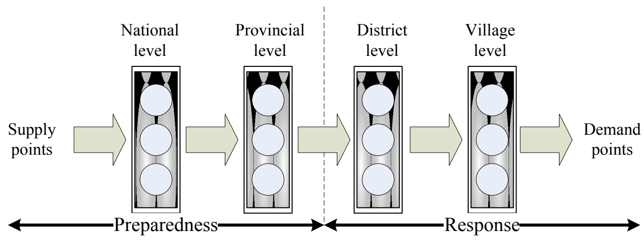

Figure 1: The assumed relief logistics network

At the first stage (preparedness stage), the locations of the national and provincial level facilities should be determined based on the delivery cost and time. These facilities are used to stock up relief supplies during normal time. Therefore both cost and time should be considered in the objective function to ensure that relief supplies are distributed at the least time possible with minimum cost. Criteria that are used to determine whether a province is disaster-prone are the province's disaster history, which aspects are:

- Severity of the disaster (number of people affected and dead casualties),
- Frequency of disaster, and
- Diversity of disaster: flood, drought, volcanic, seismic, typhoon, etc.

Based on disaster data and people density data, BNPB has developed disaster-prone index for all provinces in Indonesia and disaster-risk index of all provinces for certain disaster, such as earthquake, volcano eruption, landslide, forest fire, and flood (BNPB, 2010b). These indexes can also be used to determine which provinces that should have relief logistics facilities.

Also at this stage, based on the disaster history of a province, the list of potential locations for the district and village level facilities must be known. The selection of potential locations is based on:

- Easy transportation access to the potential locations, and
- Security in the area.

At the second stage (response stage), the exact locations of the relief logistics facilities at the district and village levels are determined. As can be concluded from Section 3, most parties have permanent facilities at the national/regional and provincial levels; however they rely on local authority judgment when considering opening temporary facilities during response stage. Therefore in this research, we focus on developing models to determine temporary relief logistics facility locations during the response stage.

The proposed modeling framework for the response stage consists of two models with bottom-up approach. The objective of the first model is to determine a set of facilities at the village level (in the affected area). The proposed model is a slight modification of maximal covering location problem (MCLP, Church and ReVelle, 1974) with the objective function of maximizing the number of affected people covered by the facilities for certain periods of time. The problem of the model is to determine a set of facilities locations within the available budget, but still ensuring that travelling time from the demand points (assumed to be the locations of the refugee shelters) to the facility locations are less than the pre-determined service time (the maximum service time). Travelling time is considered instead of distance because in the post-disaster time, distance can be short but travelling time can take longer due to damages in transportation infrastructure. The solution of the first model along with other data are then become the input of the second model. The mathematical model of Model 1 has the following structure:

Maximize Number of disaster affected people (at demand points) covered by the facilities for certain periods of time

Subject to:

Eligibility of the potential locations
The available budget to setup village level facilities (this constraint can be replaced by the number of facilities that can be opened in the village)

The second model is formulated as a mixed integer programming (MIP) model and it is used to determine the relief logistics facilities at the district level. The second model is formulated as a mixed integer programming (MIP) model and it is used to determine the relief logistics facilities at the district level with minimizing the sum of relief items delivery time from provincial level to district level facilities and from district level to village level facilities. Balances of flows, capacity at each potential location and the available budget become the constraints. The mathematical model of Model 2 has the following structure:

Minimize delivery time between provincial level facilities to village level facilities
Subject to:

Balances of flows between facilities
Capacity limitation at each facility
The available budget for delivering relief supplies from provincial level facilities to village level facilities and setting-up district level facilities

Priority of each facility at the village is also considered in the objective function and determined based on the severity of the disaster impact, which aspects are ratio of the affected people to the village population, fraction of damaged buildings, and fraction of damaged transportation infrastructure. The weights of the disaster impact criteria are calculated using paired-wise comparisons from Analytical Hierarchical Process (AHP) (Saaty, 1980). The modeling approach is depicted in Figure 2.

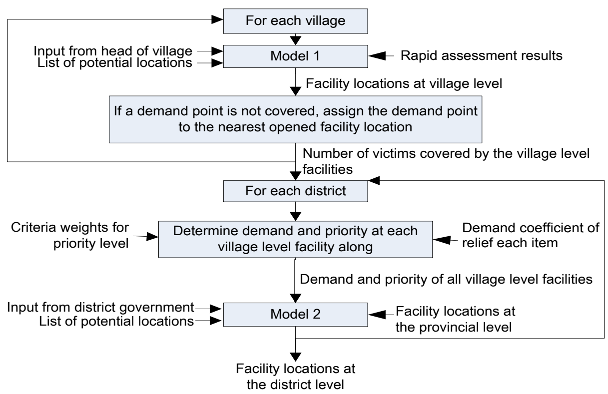

Figure 2: The modeling approach

5. CASE STUDY: THE 2007 JAKARTA FLOOD

We apply the proposed approach to analyze relief logistics network owned by Ministry of Social Welfare during the Jakarta flood in 2007 in the district of East Jakarta. The flood disaster was caused by heavy and continuous rainfall from 31 January until 3 February 2007 in Jakarta and also caused by heavy rainfall in the suburban city of Bogor, West Java, which was carried by the Ciliwung and Cisadane rivers to the city of Jakarta (Bappenas, 2007). In the district of East Jakarta, the flood affected 45 urban villages, especially in sub-district Jatinegara which located near the Ciliwung river and Cipinang creeks.

In the Jakarta province, the Ministry of Social Welfare has provincial level facility which is attached to the Division of Social Welfare. During the response stage of the flood disaster, the ministry setup temporary facilities at the urban village and district levels.

In this case study, Model 1 is used to determine the facility location at the urban village of Kampung Melayu, whereas Model 2 is employed to determine the facility location at the district of East Jakarta. Both models are solved using AIMMS 3.8.

For Model 1, the time periods considered are from 2 to 10 February 2007. The maximum service time is 15 minutes. There are two potential locations, namely the Santa Maria School (SSM) and a former cinema location called Nusantara (BN). For easier coordination, the local authority only wants to open only one village level facility.

The model is solved and the results indicate that SSM is chosen as the location as it is closer to all refugee shelters than BN. This solution is consistent with the location that the local authority chose during the flood disaster.

Model 2 is then used to find the district level facility in East Jakarta. We consider 7 urban villages: Kampung Melayu (KM), Cipinang Besar Utara (CBU), Cipinang Besar Selatan (CBS), Cipinang Muara (CM), Cawang (CW), Cililitan (CI) and Bale Kambang (BK) in two sub-districts (Jatinegara and Kramat Jati), and we consider two potential locations for district level facilities, namely a former cinema called Nusantara (BN) and the Sub-Division of Social and Welfare in East Jakarta (SDW-JT).

Time periods considered in the model is from 2 to 10 February 2010 (daily), and it is assumed that trucks are used to deliver relief goods from provincial level village level facilities. Delivery cost is approximated using the published rate of a logistics company. The relief goods considered are rice, instant noodle, and preserved food. The amount of each relief item needed by the victim is assumed based on guidance for disaster advocates from Walhi Yogyakarta (2008) and interview with representative from the Ministry of Social Welfare.

To determine the priority level of the village level facility, it assumed that fraction of victims relative to the village population is weakly more important than fraction of damaged buildings, and weakly more important than fraction of damaged transportation infrastructure. Fraction of damaged buildings, on the other hand is considered to be as important as fraction of damaged transportation infrastructure.

The model is solved and the results indicate that a former cinema called Nusantara is chosen as district level facility. The solution is consistent with the location that the local authority chose during the flood disaster.

6. CONCLUSIONS

Many organizations are involved in managing disaster in Indonesia. Those organization are governmental ministries and agencies, PMI and NGOs. Even though the government has established an agency for disaster management, BNPB, as the policy maker and the main coordinator in the event of major disaster, coordination of relief operation still face problems like undersupply/ oversupply of relief goods in the affected area. Therefore, there should be a cooperation agreement between all parties involved so that all the facilities can be used together in the relief operation, especially during the major disaster event.

We proposed hierarchical models to determine relief logistics facilities during the response stage of the disaster management cycle and applied the models to determine temporary facility locations of district and village level facilities in the district of East Jakarta during the Jakarta flood in 2007. The results show that the locations chosen by the models are consistent with the locations chosen during the actual even.

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AUTHOR BIOGRAPHIES

Ratih Dyah Kusumastuti is a Lecturer at the Department of Management, Faculty of Economics and Business, University of Indonesia. She obtained her PhD degree from Nanyang Technological University in 2006. Her teaching and research interests is in the area of operations management, especially logistics and supply chain management. She can be reached at <ratih.dyah@ui.ac.id>

Sigit Sulistiyo Wibowo is a Lecturer at the Department of Management, Faculty of Economics and Business, University of Indonesia. He obtained his master degree from University of Indonesia in 2006. His teaching and research interests include finance, risk and operations management. He can be reached at <sigit.sw@ui.ac.id>

Rizqiah Insanita is a Researcher at the Management Institute, Faculty of Economics and Business, University of Indonesia. She obtained his master degree from University of Indonesia in 2005. Her teaching and research interest is in the area of operations management. She can be reached at <rinsanita@lm.feui.org>