Last Mile Distribution in Relief Distribution Planning for Responding a Probable Tsunami

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Abstract

Due to time restrictions for conducting an emergency response, it will be not enough time for a disaster manager to provide an efficient and effective relief operation in case a preparedness plan regarding response operation has never set up. This study is aimed to develop a relief distribution plan for responding a probable tsunami by considering a limitation of supplies, resources, and response time. The Last mile distribution approach concerning the final stage of a relief chain structure that minimizes the transportation cost and penalty cost related to the victims' dissatisfactions cause of inequalities is applied in facing Sumatera Megathrust.

Keywords: Last mile distribution; Sumatra megathrust; disaster logistics; equitability; relief distribution

1. Introduction

Indonesia is located between three active tectonic plates; Indo-Australia, Eurasia, and Pacific plate. This geographical circumstances affect to the country's vulnerability of natural disaster such as earthquake, tsunami, and volcanic eruptions. Badan Nasional Penanggulangan Bencana (BNPB), Indonesian's national agency for disaster management, has mapped disaster risk index of cities in Indonesian to illustrate the risk level of each city to a disaster.

West Sumatra is one of provinces gaining the high index of vulnerability to disaster hazards. Today, West Sumatra is facing the tremendous hazard called Sumatra Megathrust. It has been predicted that an earthquake with magnitude 8.8RS would trigger an 8-10 m height of tsunami and reaching 2-5 km from the shoreline [1]. This hazard threaten almost one million people who live in seven coastal cities of West Sumatra including Padang, Pesisir Selatan, Pariaman, Padang Pariaman, Mentawai, Pasaman Barat, Agam. Moreover, the potential loss is forecasted equal to the 2004 Asian tsunami [2].

Soon in the aftermath, it is required to perform relief aid operation to fulfill the needs of the victims in order to save lives and to reduce human suffering. Though relief distribution is performed in response period but an operation plan could be set up prior to a disaster. There will be not sufficient time for the disaster authorities to organize activities related to the efficiency and effectiveness of the relief aid distribution in case of they never made the comprehensive preparedness to response the disaster in advance [3]. Actually, relief distribution is one of three aspects in humanitarian logistics (facility location, relief prepositioning stocks, and relief distribution) [4]. Humanitarian logistics is logistics that relates to humanitarian aspect. Though the government has included the logistics aspect in the West Sumatera's tsunami contingency plan, particularly the relief aid distribution plan is still not under the consideration of local government of West Sumatra province.

This research is aimed to develop a relief aid distribution plan in facing Sumatra megathrust by considering limitation of supplies, resources, and victims' vulnerabilities in order to minimize the transportation cost and the penalty cost related to the beneficiaries' dissatisfaction. Hence, delays and inequalities in the basic needs fulfillment can be minimized. This study is applied to two of the affected cites that is Pariaman and Padang Pariaman. Geographically, Pariaman is surrounded by Padang Pariaman.

2. Model Formulation

2.1. System Description

This study applies the last mile distribution model utilized for designing a relief distribution plan for Pariaman and Padang Pariaman. The model was developed by [5] considered a situation that usually occurs during a disaster such supplies, resources, and time restrictions. The objective function of the model is to minimize the transportation cost and the penalty cost related to the victims' dissatisfactions.

Demand characterization

Due to the tremendous effect of disaster, there are some factors leading to the great variation of required items such as the type and impact of the disaster, demographics, and social and economic conditions of the area. In order to cope with these conditions, it is possible to categorize emergency relief items into two main groups:

a. Type 1

Type 1 items are considered as critical items occurring once at the beginning of the emergency period such as tents, blankets, tarpaulins, jerry cans, and mosquito nets. Due to supply unavailability and vehicle capacity limitations, it may be impossible to meet all type 1 demands within a short period of time since the demand for type 1 items is typically very large. Hence, a penalty charge is applied and the costs accumulate over time for each unit unsatisfied (backordered). Therefore type 1 items will be immediately distributed to aid recipients once it arrived.

b. Type 2

Type 2 items occur periodically over the planning horizon which is considered as the items that are consumed regularly such as food and hygiene kits. The unsatisfied demand of type 2 items cannot be backordered, rather it is lost and penalty costs occur for each unit of lost demand.

Vehicles and routes

Particularly in the early days following a disaster, the most significant constraints in the last mile refers to the transportation capacity and supply availability. The vehicle fleet is unable to be optimized in the relief system, in terms of number, capacity, and compatibility. Hence, it is assumed that the vehicle fleet consists of limited number of vehicles with different characteristics. Each vehicle is differentiated based on capacity, speed, and compatibility with various arcs in the network and can load both type 1 and 2 items. Finally, the vehicle is assigned to complete multiple deliveries and to visit each demand location multiple times in a single planning period.

Planning horizon

The unpredictability related to resource levels over time becomes a unique characteristic of the last mile distribution system. It is difficult to obtain exact supply information (times and quantities). Hence, the estimation of inventory levels at an LDC for short-term period may be reliable. The great variation of vehicle availability involving its number and composition in the fleet leads to another uncertainty factor. These supply and demand related uncertainties affect to an assumption that the planning horizon will begin once the LDC is able to begin delivering relief supplies to demand locations and ends when the demand for type 1 and items are fulfilled.

2.2. Mathematical Formulation

The following notation used by Balcik et al. (2008), as follows:

T : set of days in the planning horizon; length of planning horizon
K : set of vehicles
R : set routes
N : set of all demand locations
N : set of demand locations visited on route r ∈ R
E : set of demand types : E = {1, 2}
c_{rk} : cost of route r for vehicle k ∈ K
q_k : capacity of vehicle k ∈ K (volume)
T_{rk} : duration (as a fraction of a day) of route r ∈ R for vehicle k ∈ K
d_i^1 : demand of type 1 at location i ∈ N (volume per planning horizon)
d_i^2 : demand of type 2 at location i ∈ N on day t ∈ N (volume per day)
P_{it}^1 : penalty cost factor for unsatisfied type 1 demand at location i ∈ N by day t ∈ T
P_{it}^2 : penalty cost factor for unsatisfied type 2 demand at location i ∈ N on day t ∈ T
a_t^e : amount of type e ∈ E relief supplies arriving to the LDC at the beginning of day t ∈ T
X_{rtk} : *Binary variable*, 1 if route r ∈ R is used by vehicle k ∈ K on day t ∈ T and 0 otherwise
Y_{irtk}^e: amount of demand of type e ∈ E delivered to location i ∈ N on day t ∈ T by vehicle k ∈ K via route r ∈ R
W_i^e : penalty cost associated with unsatisfied type e ∈ E demand on day t ∈ T
S_{it}^1 : fraction of unsatisfied type 1 demand at location i ∈ N by day t ∈ T
S_{it}^2 : fraction of unsatisfied type 2 demand at location on day i ∈ N on day t ∈ T
I_{it}^2 : inventory level of type 2 at location i ∈ N at the beginning of day t ∈ T

Objective function

$$Min \sum_{r \in R} \sum_{t \in T} \sum_{k \in K} crk\ Xrtk + \sum_{t \in T} \sum_{e \in E} W_t^e \quad (1)$$

Constraints

$$W_t^e \leq P_{it}^e S_{it}^e \qquad \forall i \in N, t \in T, e \in E \quad (2)$$

$$S_{it}^1 = \frac{(d_i^1 - \sum_{r:i\in N(r)} \sum_{\tau=1}^{t} \sum_{k\in K} Y_{ir\tau k}^1)}{(d_i^1)} \quad \forall i \in N, t \in T \quad (3)$$

$$S_{it}^2 = \frac{(d_i^2 + I_{i,t+1}^2 - \sum_{r:i\in N(r)} \sum_{k\in K}^{t} Y_{ir\tau k}^2 - I_{it}^2)}{(d_i^2)} \quad \forall i \in N, t \in T \quad (4)$$

$$\sum_{r:i\in N(r)} \sum_{k\in K} \sum_{t\in T} Y_{irtk}^1 \geq d_i^1 \quad \forall i \in N \quad (5)$$

$$\sum_{r\in R} \sum_{i\in N(r)} \sum_{\tau=1}^{t} \sum_{k\in K} Y_{ir\tau k}^e \leq \sum_{\tau=1}^{t} a_\tau^e \quad \forall t \in T, e \in E \quad (6)$$

$$\sum_{i\in N(r)} \sum_{e\in E} Y_{irtk}^e \leq q_k X_{rtk} \quad \forall r \in R, t \in T, k \in K \quad (7)$$

$$\sum_{r\in R} X_{rtk} \,.\, T_{rk} \leq 1 \quad \forall t \in T, k \in K \quad (8)$$

$$0 \leq S_{it}^e \leq 1 \quad \forall i \in N, t \in T, e \in E \quad (9)$$

$$I_{i1}^2 = 0 \quad \forall i \in N \quad (10)$$

$$I_{it}^2 \geq 0 \quad \forall i \in N, t \in T \quad (11)$$

$$Y_{irtk}^e \geq 0 \quad \forall i \in N, r \in R, t \in T, k \in K, e \in E \quad (12)$$

$$X_{rtk} \in \{0,1\} \quad \forall r \in R, t \in T, k \in K \quad (13)$$

2.2 Solving Methods

The relief distribution problem is solved in two phases as depicted in **Fig. 1**. Phase 1 is to generate all possible routes for delivering the relief aid, while phase 2 aims to determine delivery routes for each vehicle together with the amount of supplies to be sent to each demand point during the emergency period. Set of available vehicles, set of LDCs and demand locations, and travel time inclusive with its cost are utilized as input in phase 1 to construct the candidate of routes. In this study, the candidate of routes are obtained using the saving algorithm. The output of phase 1 together with demand needed, penalty cost, supply arrivals, and capacity of each vehicle are considered as inputs for phase 2. In the phase 2, the mathematical formulation of last mile distribution developed by [5] is implemented in order to optimize the route assignment of relief vehicles including number of relief aid to be delivered to every TEAs during the emergency period.

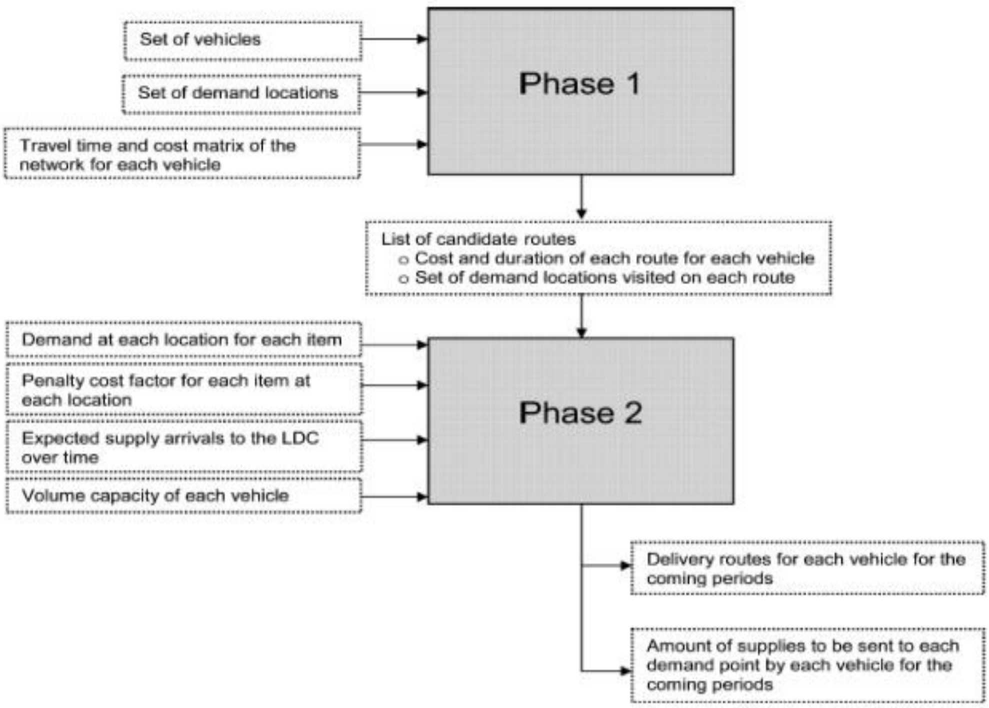

Fig. 1. Two-phase model [5]

3. Numerical Experience

The last mile distribution model is applied to Pariaman city and Padang Pariaman district which are considered as the vulnerable areas in term of dealing with Sumatra Megathrust. According to the contingency plan of West Sumatra Province to deal with Sumatra megathrust hazard, hence the planning horizon for fulfilling the needs in Pariaman city and Padang Pariaman district is set to be 14 days [1]. Padang Pariaman district have established one LDC for each area which has access to the affected area by considering such as safety and security, road reliability, and transportation modes [6] and [7] as well as Pariaman city [8]. The demand locations which are also called as TEA are set by considering evacuation routes developed by the local government. We assume that every evacuee will shelter themselves to the nearest TEA, hence there are 10 selected TEAs in Pariaman city (**Fig. 2.**) and 5 selected TEAs in Padang Pariaman district (**Fig. 3.**), respectively.

Fig. 2. Potential TEAs in Pariaman city

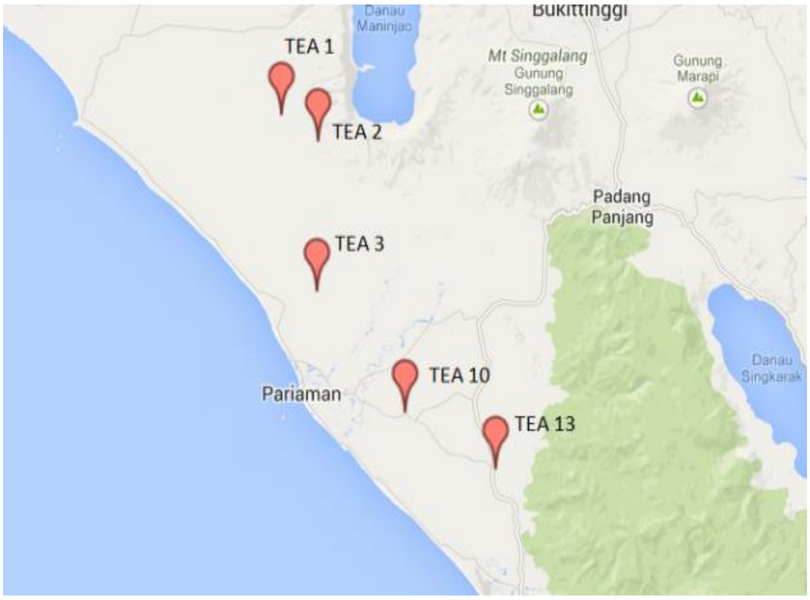

Fig. 3. Potential TEAs in Padang Pariaman district

The estimation of evacuees sheltering in every demand points is obtained by determining average number of household including its family members and vulnerable people in order to fit the demand needs into relief package to be delivered to every TEAs. The total number of evacuees in Pariaman city are estimated to be 17,322 people and 14,975 people in Padang Pariaman district, respectively. The dimension of relief package is set to be 1 m^3 for each type 1 and 2 items in order to simplify from determining vehicles' capacity. Type 1 items consist of clothes, blankets, petroleum, tents, mats, family kits, food ware, kid ware, and women's ware. Meanwhile, type 2 items consist of instant rice, side dishes, and mineral water (Table 1).

Due to number of evacuees in Pariaman city and padang pariaman district contribute to 3% of total victims, we assume that the allocation of relief vehicles will be 3% for each Pariaman city and padang pariaman district from total number of available vehicles. Those are pick up car (four wheels), medium truck (six wheels), big truck (10 wheels), and helicopter (Table 2).

The mathematical formulation of the problem is solved using LINGO 14.0 software. Solution gained by this calculation is optimal global. Based on the optimization result by using LINGO software, it is found that all of relief aids type 1 of Pariaman city and Padang Pariaman district are being fulfilled each in the 13th and 12th in the emergency period. Meanwhile, the relief aid type 2 belonging to basic needs will be satisfied in every period in the planning horizon. Due to the urgency of type 2 items to be immediately satisfied, hence the type 2 items fulfillment will be prioritized. From the optimization result, we found that the relief aid distribution cost of Pariaman city is 1,805,338,500 IDR which is more expensive than Padang Pariaman district gaining 1,100,661,721 IDR (Table 3). The relief aid distribution plan for Pariaman city in the day-1 is depicted on Table 4.

Table 1. Type of items

Type	Items	Unit	Requirement	Total requirements	Volume per package (m^3)
1	Clothes	Package/household	1	1	0.017
	Blanket	Sheet/head	1	1	0.003
	Petroleum	Gallon/household	1	1	0.014
	Tent	Package/household	1	1	0.14
	Mat	Package/household	1	1	0.009
	Family kit	Package/household	1	1	0.075
	food ware	Package/household	1	1	0.05
	kid ware	Package/infant	1	1	0.011
	women's ware	Package/woman	1	1	0.017
2	instant rice	Package/household/3 days	1	5	0.032
	side dishes	Package/household/3 days	1	5	0.032
	mineral water	bottle/day/head	3	42	0.001

Tabel 2. Available vehicles

No	Vehicle	Operational cost (IDR)	Vehicle allocation		Vehicle's capacity (package)		Total loading and unloading time/vehicle (hr)	Total loading and unloading cost/vehicle (IDR)
			Pariaman city	Padang Pariaman district	Pariaman city	Padang Pariaman district		
1	Pick up car	2,100/km	1	1	6	6	0.35	354,911
2	Medium truck	4,310/km	5	5	14	14	1	1,000,000
3	Big truck	6,731/km	1	1	32	32	1.5	1,500,000
4	Helicopter	2,000,000/hr	-	1	-	1	0.06	59,152

Table 3. Total relief distribution cost

Area	Vehicle	Routing cost (IDR)	Penalty cost (IDR)	Total cost (IDR)
Pariaman city	Big truck	1,170,074,000	635,264,500	1,805,338,500
	Medium truck (MT) 6a			
	Medium truck (MT) 6b			
	Medium truck (MT) 6c			
	Medium truck (MT) 6d			
	Medium truck (MT) 6e			
	Pick up car			

Padang Pariaman district	Helicopter	5,089,821	600,000,000	1,100,661,721
	Big truck	495,571,900		
	Medium truck (MT) 6a			
	Medium truck (MT) 6b			
	Medium truck (MT) 6c			
	Medium truck (MT) 6d			
	Medium truck (MT) 6e			
	Pick up car			

Table 4. Relief distribution plan in Pariaman city for the 1st day

Item Type – ½	Camp visited	1	2	3	4	5	6	7	8	9	10
Big Truck	5-1-2-3-8	0/4	3/0	15/0		7/0			3/0		
	6-7-9-10									9	1
M.T 6a	3-8			0/1		2	20				
	2-8		0/3								
M.T 6b	3			0/14							
	9									0/14	
M.T 6c	5-1-4	4/0			0/5	5/0					
	7						0/14				

4. Conclusions and Future Research

This research carried out the relief aid distribution plan for facing Sumatra megathrust by utilizing last mile distribution model in Pariaman city and Padang Pariaman district. The applied model has considered equity concept in the delivery process. It costs 1,805,338,500 IDR for 17,322 beneficiaries in Pariaman city and 1,100,661,721 IDR for 14,975 beneficiaries in Padang Pariaman district. The total penalty cost applied related to victims' dissatisfaction of relief aid shortage and inequality has also contributed to the total relief aid distribution cost.

The future research may be developed by utilizing decision support system of relief aid distribution to the beneficiaries in order to shorten decision-making process.

Acknowledgement

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