Design of transportation system of humanitarian aids logistic using variable neighborhood search (VNS) algorithm: Case study in Merapi eruption

by Naniek Utami Handayani

Design of Transportation System of Humanitarian Aids Logistic Using Variable Neighborhood Search (VNS) Algorithm: Case Study in Merapi Eruption

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Abstract. Disaster management is a dynamic, sustained, and integrated process to improve the effectiveness and efficiency of activities related to the prevention, mitigation, preparedness, early warning, emergency response, rehabilitation, and reconstruction of the disaster. During the emergency phase, the transportation of humanitarian aids logistic must be properly managed in order to arrive on time and suit with the type and number of needs at each location of evacuation. During Merapi eruption in 2010, there were problems in the distribution of disaster logistic. They included the delay and the mismatch amount and types of relief goods at any location of evacuation. It is mainly due to the absence of transportation system planning to distribute disaster logistic owned by BPBD Sleman. The research aims to improve the system transportation of disaster logistics at the emergency response in order to minimize the unfulfilled demand and transport time using the algorithm Variable Neighborhood Search (VNS). The VNS algorithm is a meta-heuristic algorithm to solve combinatorial and global optimization. The basic idea of this algorithm is a systematic change of neighborhood with local search. The research resulted in four tours that optimally match the objective function with two trucks and two pick-ups.

INTRODUCTION

Disaster management is a dynamic, sustained, and integrated process in order to improve the effectiveness and efficiency of activities related to the prevention, mitigation, preparedness, early warning, emergency response, rehabilitation, and reconstruction of the disaster. Disaster is a term that refers to a physical disorder that affects the system as a whole and threatens the priorities and goals [1, 2]. Disasters can be divided into two general categories, i.e. natural disaster and disaster caused by human or technological error. Based on the cause, disasters can be divided into natural disasters and man-made disasters. Meanwhile, based on the speed of the occurrence time, disasters can be divided into sudden onset and slow onset [1, 2].

The impact of natural disasters is largely seen in the perspective of human life and their livelihood. The emergency response, recovery, and rehabilitation require enormous resources (e.g., disaster relief goods, funding, and personnel) that depend on the scale of damage and the type of disaster. Disaster response efforts are considered highly uncertain and complex, it must be managed properly in order to obtain faster responses. Thus, disaster management is very important, because it encourages the successful implementation of emergency response that begins with strategic planning of emergency response [2, 3].

Six approaches to disaster research include geographical, anthropological, sociological, developmental, medical and technical [4]. Disaster management is an activity designed to maintain and oversee the event of disasters and emergencies as well as to provide assistance in order to avoid or recover from the impact of a disaster [5]. In any type of disaster, the steps as disaster response are generally composed of 4 (four) phases [6], namely, mitigation, preparedness, response, and recovery. Characteristics of disaster management logistics are certainly different from the characteristics of commercial logistics in general, one of the characteristics is that the main purpose of disaster relief logistics activity is to alleviate the suffering of disaster victims [7].

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Yogyakarta is one of the provinces in Indonesia, located in areas prone to volcanic eruption. In Sleman, Yogyakarta, Mount Merapi as one of the most active volcanoes in Indonesia is located [8]. This conditions lead to high chances of natural disasters including volcanic eruptions and volcanic earthquakes. The frequency of volcanic eruptions is high at an average of 2-5 years in the last 100 years. The danger level of Mount Merapi is very high due to the density of the population living around the slopes of Mount Merapi. It is shown in the data of the dead victims as a result of the eruption of Mount Merapi in 2010, which reached 353 people. According to the Head of Hazard Mitigation of BPBD Sleman, Merapi eruption in 2010 resulted in an open lava dome leads to the East, hence in case of the eruption of Merapi lava predicted would lead to Gendol River located in Sleman.

In general, the mitigation of natural disasters in Indonesia is still responsive and reactive to sudden disasters that may occur. It shows that disaster management system is not well coordinated and cannot be quickly intervening response to disaster mitigation. To be more precise, effective, and efficient, integrated natural disaster management system that includes the management of disaster logistics system should be designed. One aspect that is very important in disaster management is an effective and efficient disaster transportation logistics. The entire disaster relief items should be distributed as soon as possible, so it is necessary to build a transportation system for disaster relief items. Based on the interviews with the local community in Cangkringan, Sleman Yogyakarta, there are few complaints about the distribution of disaster relief during an eruption in 2010. The complaints, among other, are delays in delivery of disaster relief goods especially in the beginning of the eruption, logistic humanitarian aids given as emergency response, and the amount of the received relief goods did not match the number of refugees at the camp.

RESEARCH METHODS

Research Design

Logistics Management Disaster

According to [9], logistics (in the context of disaster) or often referred to disaster relief operations (DROs) include an assessment of demand, procurement, prioritization, receiving goods, sorting, storage, retrieval and delivery. The concept is similar to supply chain management (SCM) for commercial purposes in the business world. Previous researchers have discussed the concept and implementation of SCM for commercial purposes. However, the concept and implementation of the DRO have not been much discussed, and it provides an opportunity to study it comprehensively. Both concepts have similarities, in which in principle, SCM approaches and techniques used for commercial purposes can be used as a reference for the development of the concept of DROs.

The basic logistical problem for disaster relief operations is to distribute a number of different commodities using a number of different modes of transportation, from a number of origins to one or more destinations over a transportation network in a timely effectively and efficiently. This is a multi-commodity, multi-modal network flow problem with time windows, which is one of the most complex network flow problems in operations research [10].

Vehicle Routing Problem (VRP)

The vehicle routing problem is a method for the determination of transport routes of goods distribution that aims to get the optimal route [11, 12], in which the maximum capacities of the used vehicles have been known. Analysis based on this method is expected to fulfill the customer's demand on the locations and the number of demands that have been known. A route is considered as optimal if the route meets certain operational obstacles, i.e., have the total distance and the shortest travel time and use a limited number of vehicles.

Sequential Insertion Algorithm

According to [13, 14], there are two methods to form a VRP solution, namely by combining the existing route with the saving criterion and making a sequence to enter subscribers in the vehicle by using the criteria of cost insertion. According to [15], the second method has proven to be more popular to solve vehicle routing and scheduling problems. This algorithm builds a feasible solution, which is a set of the feasible route by way of repeated attempts to enter a customer who has not entered into any service to the part while the current route is formed.

Variable Neighborhood Search (VNS) Algorithm

The Variable Neighborhood Search is a meta-heuristic algorithm to solve combinatorial and global optimization problem which basic idea is the systematic change of neighborhood with local search [16, 17, 18]. Another meta-heuristic is usually based on basic ideas or analogies developed afterward. The generated heuristic is often complicated and containing many parameters. It can increase the efficiency but obscures the original destination. Variable Neighborhood Search (VNS) is based on a simple principle, namely the systematic changes to the neighborhood with a local search.

Conceptual Model

The conceptual model in this study refers to Ahmadi et al. [19] by adjusting the conditions in Sleman. The objective function of this study is to minimize the occurrence of shortcomings in the fulfillment of demand and minimize transportation time in order to avoid delays. Determination of the objective function is based on the research objectives and problems in the field. Based on preliminary studies, the problems that arise are the delays in the arrival of relief goods and the shortcomings in the fulfillment of demand. The lack of disaster logistics, in terms of quantitative, has caused the seizure of logistics among refugees. Therefore, this study focused on demand fulfillment and freight transport of relief goods. Characteristics of VRP are described as follows and the conceptual model of this study is presented in Figure 1.

Single product (SP)

The shipped items are disaster relief goods. The product is packaged in one bag and measured in units of kilograms. Aid packages contain food packages, clothing packages and other logistic packages based on the Regulation of the Head of BNB No. 18 of 2009 [19]. Demand is set at 6.315 kg.

Heterogeneous Fleet (HF)

BPBD vehicles are available in Sleman district, consisting of two types of vehicles with different capacities. They consist of 2 (two) trucks and 2 (two) pick-ups.

Single Depot (SDT)

Warehouse logistics support is located in Sleman, as many as one warehouse.

Time Windows (TW)

Planning time horizon in this study is based on the standard 8-hour relief time (SRT) [19].

Split Delivery (SD)

Delivery of products can be made in one or several times of shipping based on the condition of the vehicle and the capacity of the shipping process.

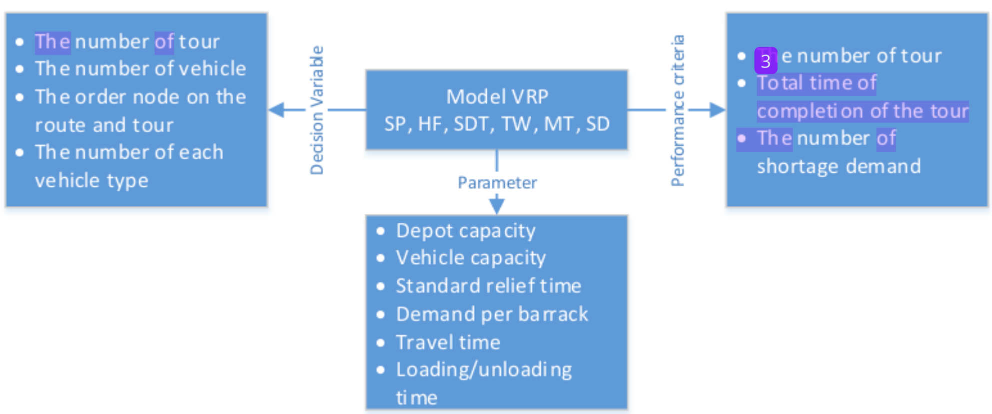

FIGURE 1. The Conceptual Model.

Formulation

Formulation of mathematical model in this research refers to [19] as expressed as follows:

a. Set

$J = \{1,2,\ldots,|J|\}$ is set the site, $N = \{1,2,\ldots,|J|, |J|+1\}$ is set all the network, $V = \{1,2, .., |V|\}$ is set vehicle, $K = \{1,2, .., |K|\}$ is set tour, $G = \{1,2, .., |G|\}$ is set relief goods, $P = \{1,2, .., |NL_{[k,r,v]}|\}$ is set position.

b. Parameter

Q is warehouse capacity, q is vehicle capacity, srt is standard relief time, d_{jg} is demand of node "j" for relief goods "g", t_{nm} is travel time of node "n" to node "m", t_{LT} is time of *product loading*, s_{nm} is distance of node n to node m, ve is vehicle speed, C is the number of customer, $Jm_{k,v,r,p}$ is departure time to p position, route r on the tour, $Js_{k,v,r,NL[k,r,v]}$ is finish delivery time in 1 tour and LT is *loading* speed.

c. Binary variable

x_{nmk} is 1 if node "m" that is visited after node "n" in tour "k", and 0 otherwise, lkv is 1 if vehicle "v" that be used for tour "k", and 0 otherwise.

d. Continuous Variables

μ_{jg} is the number of relief goods "g" that deliver to node "j" and γ_{gij} is the number of demand of relief goods "g" not yet fulfilled from depot "i" to *node* "j".

e. Decision variable

NV is the number of total vehicle (unit), NK is the number of tour, NR[k,v] is the number of route r in tour k by vehicle v and NL[k,r,v] is the number of location in route r in tour k by vehicle v.

f. Performance criteria

TCT is Total time for finish a tour and γ_{gij} is the number of demand of relief goods "g" not yet fulfilled from depot "i" to *node* "j".

Formulation of Mathematical Model

Objective function

This research has two objective functions, i.e., to minimize delivery time and to minimize shortage demand. The objective functions are described as follow.

$$\text{Min } Z = \omega_{\gamma_{gij}}.\gamma_{gij} + \omega_{TCT}.TCT \quad (1)$$

Based on equation 1, the weighted number of γ_{gij} and *TCT* is weighed from the factors (`$\omega_{\gamma_{gij}}$ and ω_{TCT}), which is 1.000 and 10, respectively. Of these two factors, namely the priority assigned as the first priority is to minimize γ_{gij}, where the demand is not met in accordance with the number of customer demand that is reduced by the amount of goods shipped to customers in the service. While touring total completion time (TCT) is obtained from the total sum of completion times CT_k of all tours.

$$\gamma_{gij} = \sum_{j\in J} d_{jg} - \sum_{j\in J} \mu_{jg} \quad (2)$$

$$TCT = \sum_{k=1}^{K} CT_k \quad (3)$$

Completion time

Completion time CT_k is the result of addition loading time and travel time stated as follows:

$$CT = t_{nm} + t_{LT} \quad (4)$$

Completion time is equal to the time of the finished tour: $Js_{k,v,r,NL[k,r,v]}$

$$CT_k = Js_{k,v,r,NL[k,r,v]} \quad (5)$$

Travel time

The travel time is obtained from the distance between the barracks divided by the speed of the vehicle expressed by:

$$t_{nm} = \frac{s_{nm}}{ve} \tag{6}$$

Loading time

$$t_{LT} = \frac{\mu_{g,k,r,p}}{LT} \tag{7}$$

Departure time

Departure time of vehicle v in delivery relief goods on route r, tour k form depot or barrack location $Jm_{k,v,r,p}$ finish time for customer (barracks) in the previous location:

$$Jm_{k,v,r,p} = Js_{k,v,r,p-1]} \tag{8}$$

Subject to:

$$\sum_{m\in N} x_{nmk} = \sum_{m\in N} x_{mnk} \ (\forall n \in N, k \in K) \tag{9}$$

This equation ensures that the number of vehicles that depart and return from and to the depot are the same,

$$\sum_{j\in J} x_{jik} \leq 1 \ (\forall k \in K) \tag{10}$$

This equation ensures the sustainability of each route and return to the depot early,

$$\sum_{v\in V} l_{kv} \leq 1 \ (\forall k \in K) \tag{11}$$

This equation ensures that every tour is served by one vehicle,

$$TCT \ \leq srt \tag{12}$$

This equation ensures that the completion time of the tour by vehicle does not exceed the standard relief time of 8 hours,

$$\sum_{j\in J} \sum_{g\in G} \mu_{jg} \ \leq Q \tag{13}$$

Equation 13 is a condition that ensures the capacity demand of all tours served by the depot does not exceed the capacity of the depot,

$$\sum_{g\in G} \mu_{jg} \ \leq q \tag{14}$$

Equation 14 is the condition of the capacity of the transport vehicle,

$$x_{nmk}, l_{kv} \in \{0,1\} \ (\forall j \in J, v \in V, n, m \in N, k \in K) \tag{15}$$

$$\mu_{jg}, \gamma_{gij} \ \geq 0 \qquad (\forall j \in J, g \in G, k \in K) \tag{16}$$

DISCUSSION

Product delivered in this study is a disaster relief package that is packed evenly for the community under the Regulation of BNPB No. 18/2009, which is identical to the standard amount of relief goods on research [20]. Table 1 is a standard amount of aid goods. Data of demand is assumed to be equal to the storage capacity of each barrack. Table 2 is a data request for each camp. Table 3 represents the distance between the data camp. The journey time between the camp and the depot is obtained from the distance between the camp and depot divided by the vehicle speed of 30 km/h. Table 4 is a time constant that is used in research.

TABLE 1. Standard of the Quantity of Logistic Aids

Type	Quantity (kg/person)
Food	1.18
Water	3
Medical Supplies	0.091
Hygiene Kit	2.044
Total	6.315

TABLE 2. Demand

Barrack	Node	Demand (person)	Demand (kg)
Wonokerto	A	200	1263
Girikerto	B	300	1894.5
Purwobinangun 1	C	300	1894.5
Purwobinangun 2	D	300	1894.5
Gondanglegi	E	1400	8841
Candibinangun	F	300	1894.5
Brayut	G	300	1894.5
Plosokerep	H	300	1894.5
Kiyaran Wukirsari	I	620	3915.3
Glagarharjo	J	100	631.5
Gayam	K	300	1894.5

TABLE 3. Distances (km)

0	A	B	C	D	E	F	G	H	I	J
8.7										
7.4	1.3									
4.3	4.7	3.4								
4.3	4.7	3.4	0.1							
4.2	4.9	3.6	3.6	3.5						
3.8	8.7	7.4	4.2	4.1	5.8					
3.0	10.7	9.4	7.0	6.9	5.8	6.6				
5.5	11.8	6.8	9.4	9.4	6.8	9.1	2.4			
3.3	11.1	9.8	7.3	7.3	6.2	7.1	1.5	2.8		
7.6	15.4	14.2	11.7	11.6	10.5	11.4	4.9	4.7	4.4	
7.7	15.3	14.0	11.5	11.5	10.4	11.3	5.6	5.3	4.2	1.7

TABLE 4. Time Constants

No	Type of Constants	Period (hours)
1	Time Horizon	8
2	Speed of truck loading/unloading	
	Truck 5000 kg	2500 kg / hour
	Pick up 1500 kg	3000 kg / hour
3	Speed of vehicle	30 km / hour

Table 5 is the recapitulation of the calculation of Variable Neighborhood Search algorithm. Calculation produces 4 (four) tours with 4 (four) vehicles. The order of vehicles of the tour 1 to tour 4 is truck-truck-pick up-pick up. The combination of these vehicles is obtained by calculating the function of demand and the function of transport as the most minimal turnaround time.

TABLE 5. Recapitulation

Tour	Vehicle	Route	Utilization (%)	Excess Demand (kg)	TCT (hour)
1	Truck	0-A-K-J-G-0-A-0	56.835	0	7.970
2	Truck	0-F-D-C-0-C-B-0	75.78	0	7.945
3	Pick up	0-H-0-H-I-0-I-0-I-E-0-E-0-E-0	100	5650.8	7.986
4	Pick up	0-E-0-E-0-E-0-E-0	94.18	0	5.012

CONCLUSION

The transport system of disaster relief goods is designed in this study with the goal of minimizing shortcomings in the fulfillment of demand and transportation time to prevent delays in the arrival of relief goods in case of eruption of Mount Merapi in Sleman district. The generated route consists of 4 (four) tours consisting of:

- The tour route of Pakem 1- Wonokerto- Gayam- Glagaharjo- Brayut- Pakem- Wonokerto- Pakem. Tour 1 uses truck with a capacity of 5000 kg.
- The tour route of Pakem 2- Candibinangun- Purwobinangun 2- Purwobinangun 1- Pakem 1- Purwobinangun Girikerto- Pakem. Tour 2 uses truck with a capacity of 5000 kg.
- The tour route of Pakem 3- Plosokerep- Pakem- Plosokerep- Kiyaran Wukirsari- Pakem- Kiyaran Wukirsari- Pakem- Kiyaran Wukirsari- Gondanglegi- Pakem- Gondanglegi- Pakem- Gondanglegi- Pakem. Tour 3 use pick-up with capacity of 1500 kg.

- The tour route of Pakem 4- Gondanglegi- Pakem- Gondanglegi- Pakem- Gondanglegi- Pakem- Gondanglegi- Pakem. Tour 4 uses a pick-up with a capacity of 1500 kg.

Vehicle required in accordance with the calculation consists of 2 (two) trucks with a capacity of 5000 kg and 2 (two) pick-ups with a capacity of 1500 kg. This amount is equal to the number of vehicles in BPBD Sleman, so the addition of vehicles to adjust the eruption case scenario is not required.

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