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by The Jin Ai

Model for determining logistic distribution center: case study of Mount Merapi eruption disaster

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Abstract. As one of the most active volcano in the earth, Mount Merapi is periodically erupted and it is considered as a natural disaster for the surrounding area. Kabupaten Sleman as one of the nearest location to this mount has to be always prepared to this disaster. The local government already set three different groups of region, in which potentially affected by Mount Merapi eruption, called KRB I, KRB II, and KRB III. Region KRB III is the closest area to the mount crater and most often affected by the eruption disaster. Whenever KRB III is affected, people live in that area usually being transfer to the next region set that is KRB II. The case presented in this paper is located at the KRB II region, which is the second closest region to the mount crater. A humanitarian distribution system has to be set in this region, since usually this region is became the location of shelters for KRB III population whenever a 'big' eruption is happened. A mathematical model is proposed in this paper, for determining the location of distribution center, vehicle route, and the amount of goods delivered to each customer. Some numerical illustration are presented in order to know the behavior of the proposed model.

1. Introduction

Disaster is a natural phenomenon that cannot be avoided. During 2003 - 2012, the worldwide average annual disaster frequency was 388, and the average annual of people killed by disasters was 106,654 [1]. Disaster not only killed of peoples, but also in the number of injured, displaced, material losses, environmental damage and psychological impact. Losses in term of financial and psychological were a matter that cannot be recovered in a short time. Therefore, preparedness is important to reduce losses, both material and immaterial.

Preparedness is an important factor to overcome disaster. Experience from any disaster events that have occurred, could be used as the basis for prevention and management of disasters. An increase in the number and impact of disasters should be a concern in disaster response operations to more efficiently and effectively [2]. The magnitude of mortality and financial losses that occur indicate the absence of good preparedness in the face of disaster. Humanitarian logistics is one kind of preparedness to be done. This activity, or usually called disaster relief operations (DRO), includes assessing demand, procurement, prioritization, receiving goods, selection, store, search and delivery. This activity is somewhat similar to commercial supply chain management [3].

As well as commercial logistics system, the humanitarian logistics system includes several stages of the disaster, preparation, planning, procurement, transportation, storage, and distribution [4]. The main difference is the main focus. In the commercial logistics system, the final consumer, which is the input source of funds of the entire supply chain, becomes the main focus. However, in the

humanitarian logistics system, the end consumer does not have participation in transaction activity, neither control of the supply. When applied to the activity of humanity, the supply chain must be flexible and able to respond quickly to events that cannot be predicted effectively and efficiently. Disaster logistics supply distribution system in contrast to the more commercial logistics focuses on the problem of costs and benefits [5]. Supply logistics of disaster in order to have a fast response and appropriate allocation in response to a disaster.

Research related to the logistics distribution model during disaster by determining the distribution center is based on a risk map has not been done. This model is necessary to help all the parties conducting disaster preparedness. The data required in the form of risk maps are now widely made and continue to be made to areas with disaster potential.

Case Study

Mount Merapi is one of the most active volcanoes in the earth. The volcano periodic activities that can be a natural disaster for the surrounding area is its eruption. Since the eruption is frequently happened, Kabupaten Sleman, which is located in Yogyakarta Province, Republic of Indonesia, has to be prepared to this disaster, since some regions of Kabupaten Sleman are placed next to this mountain. The local government already sets three different groups of region, in which potentially affected by Mount Merapi eruption, called KRB I, KRB II, and KRB III. It is noted that KRB III is the closest area to the mount crater and most often affected by the eruption disaster. Whenever KRB III is affected, people live in that area usually being transfer to the next region set that is KRB II.

Our case are focus on the KRB II, in which during the disaster people live in this region combined with the people from KRB III are gathered into some centralized shelters for effective disaster mitigation. For example, if the scale of eruption is increasing and the KRB II region became affected, the transfer of people to safer region, i.e. KRB I, can be coordinated and performed effectively. Another example is the distribution of humanitarian aid to the affected people can be conducted efficiently. Based on several occasion of this eruption, it is required to have a big depot or logistic distribution center for serving the shelters in KRB II. This depot responsibility is to handle the humanitarian aid received from many different stakeholders and distribute the aid to all shelters. For effectively coordinate the shelters, the government set village administrator as the coordinator all shelter within their village. Hence, the common flows of humanitarian aid in this stage are depot – village administrator office – shelter. The current village administrator offices in the KRB II are described in Table 1, together with population estimation of each village.

Table 1. Village, GPS coordinate of the administrator office, and demand estimation in KRB II

No	Village	GPS Coordinate	Population Estimation
2	Girikerto	(-7.6242265, 110.3911628)	946
3	Wonokerto	(-7.6207774, 110.3829727)	590
4	Purwobinangun	(-7.6492907, 110.3923309)	814
5	Candibinangun	(-7.6633180, 110.3993969)	580
6	Hargobinangun	(-7.6397432, 110.4258035)	3912
7	Wukirsari	(-7.6577791, 110.4438001)	1826
8	Argomulyo	(-7.6594539, 110.4563488)	4254
9	Kepuharjo	(-7.6251696, 110.4524367)	7104
10	Umbulharjo	(-7.6257874, 110.4332686)	2040
11	Sindumartani	(-7.6915330, 110.4761452)	599

Other problems that usually rose during the distribution of humanitarian aid are related to the route of distribution vehicles and the distribution service level. For this case, the local government is

allocated only single distribution vehicle for serving the KRB II area. Therefore, the scheduling of this vehicle is very important so that all the villages in the area can be covered within the operational time. Related to the service level, it is common in this situation that the supply of humanitarian aid available to be distributed is less than the total demand of the aid for all villages. As consequences, the service level may less than 100%. There is a necessity to make the service level among village are balanced so that every village are experienced more or less the same quality of fondness from various stakeholders during the time of disaster. In an extreme situation, distribution that make 100% service level to village A and 0% service level to village B can lead to chaotic condition since the people in village B are felt abandoned, jealous to the people in village A, and think that the government is unfair to them. By creating balance of the service level, therefore, the last illustration can be avoided.

3. Mathematical Model

Based on the case described above, we can formulate a mathematical model for determine the location of logistic distribution center, the vehicle route, and the amount of goods delivered to each customer location.

In order to determine the logistic distribution center, we are using center of gravity approach. The formula to obtain the center are

$$\bar{x} = \frac{\sum x_i \varphi_i}{\sum D_i} \tag{1}$$

$$\bar{y} = \frac{\sum y_i \varphi_i}{\sum D_i} \tag{2}$$

where

$\bar{x}$: x coordinate of the logistic distribution center
$\bar{y}$: y coordinate of the logistic distribution center
x_i : x coordinate of village administrator office i
y_i : y coordinate of village administrator office i
φ_i :   population estimation of village i

A mixed integer linear programming is formulated in order to simultaneously the vehicle route and the amount of goods delivered to each customer location. It is defined that the customers are located in each village administrator office. Several assumptions for this formulation are:

- Number of customer location is known
- Each customer location can be visited once in each vehicle route
- Vehicle has access from the distribution center to every customer location and from every customer location to other customer locations
- Every vehicle route starts from and ends at the distribution center
- The distance is symmetric, i.e. the distance from customer i to customer j is equal to the distance from customer j to customer i. Hence, the travel time is also symmetric
- Whenever vehicle is completing its service to a certain route, it can be assigned to serve another route as long as its total time is not exceeding the service time availability
- The amount of goods delivered to each customer is not exceeding its corresponding customer demand
- Travel time is deterministic static
- Loading and unloading time in every location is similar and constant

The model is formulated with two set of decision variables:

- Q_{jr}, amount of goods delivered to customer j by vehicle r
- X_{ijr}, a binary variable indicating the vehicle route, in which $X_{ijr} = 1$ whenever vehicle r travel to location j right after location i and $X_{ijr} = 0$ for other conditions

The mixed integer linear programming is formulated using two sets definition which are the set of location J and set of vehicle route R. The member of set J are the distribution center (set as $j=1$) and all the customer location (set as $j=2,3, \dots$)

The model is presented below:

$$\text{Min } \sum_{j \in J}\left(D_j - \sum_{r \in R} Q_{jr}\right) \tag{3}$$

Subject to

$$\sum_{r \in R} Q_{jr} \leq D_j, \qquad \forall j \in J \tag{4}$$

$$\sum_{r \in R} \sum_{j \in J} Q_{jr} \leq S \tag{5}$$

$$\sum_{j \in J} B.Q_{jr} \leq W, \qquad \forall r \in R \tag{6}$$

$$\sum_{j \in J} V.Q_{jr} \leq G, \qquad \forall r \in R \tag{7}$$

$$\sum_{r \in R} \sum_{i \in J} \sum_{j \in J}\left(P_{ij} + \tau\right).X_{ijr} \leq L \tag{8}$$

$$X_{ijr} + X_{hir} \leq 1, \qquad \forall i > 1, \forall j > 1, i \neq j, \forall h > 1, h \neq i, \forall r \in R, \tag{9}$$

$$\sum_{j \in J} X_{1jr} = 1, \qquad \forall r \in R \tag{10}$$

$$\sum_{i \in J} X_{i1r} = 1, \qquad \forall r \in R \tag{11}$$

$$\sum_{i \neq h} X_{ihr} = \sum_{h \neq j} X_{hjr}, \qquad \forall i \in J, \forall j \in J, \forall r \in R \tag{12}$$

$$F_j = \frac{\sum_{r \in R} Q_{jr}}{D_j}, \qquad \forall j \in J \tag{13}$$

$$A = \frac{\sum_{j \in J} F_j}{|J|}, \tag{14}$$

$$A - \delta \leq F_j \leq A + \delta, \qquad \forall j \in J \tag{15}$$

$$X_{ijr} \in \{0,1\}, \qquad \forall i \in J, \forall j \in J, \forall r \in R \tag{16}$$

$$Q_{jr} \geq 0, \qquad \forall j \in J, \forall r \in R \tag{17}$$

where

D_j	:	demand of customer j
S	:	supply of goods in the logistic distribution center
B	:	unit weight of goods
W	:	weight capacity of distribution vehicle
V	:	unit volume of goods
G	:	volume capacity of distribution vehicle
P_{ij}	:	travel time from location i to location j
τ	:	loading and unloading time
L	:	volume capacity of distribution vehicle
F_j	:	service level of customer j
L	:	average service level
δ	:	service level balance factor

The objective function of this formulation, which is presented in equation (3), is to minimize total unmet demand for all customers. Constraint in equation (4) states that the amount of goods delivered to each customer is not exceeding its corresponding customer demand. Equation (5) states that the total amount of goods delivered to customers is not exceeding the supply of goods in the logistics distribution center. Constraint (6) and (7) explain the limitation of vehicle in term of weight and

volume, respectively. The equation (8) states the total service time limitation of vehicle including loading and unloading time. Equation (9) is defined to limit number of vehicle visit to each customer in each route, which is only single visit allowed. The logic of routes are described in constraints (10)-(12), in which the route starts and ends at the distribution center. Moreover, whenever a route enters a customer, it also departs from it. Constraints (13)-(15) are set for making the service level among customer are balanced. Constraints (16) and (17) limit the variables value.

4. Solution of the Case
Based on the data in Table 1, the calculation of equations 1 and 2 are resulting the location of logistic distribution center which is (-7.6402453, 110.4388979). Therefore, the travel time from this center to various village administrator offices and the travel time among office can be determined using common GPS service map, i.e. the Google Maps®. The travel times are summarized in Table 2, in which '1' denotes the logistic distribution center and '2' to '11' denote the customers, which are the village administrator office 2 to 11, respectively.

Table 2. Travel time from one location to other location (in minutes)

	1	2	3	4	5	6	7	8	9	10	11
1	0	27	29	21	19	13	6	7	8	7	17
2	27	0	3	7	11	18	22	26	30	24	33
3	29	3	0	9	13	21	24	28	31	26	35
4	21	7	9	0	5	13	16	21	23	18	28
5	19	11	13	5	0	17	15	19	22	17	26
6	13	18	21	13	17	0	14	16	10	5	25
7	6	22	24	16	15	14	0	5	10	9	13
8	7	26	28	21	19	16	5	0	8	11	9
9	8	30	31	23	22	10	10	8	0	5	17
10	7	24	26	18	17	5	9	11	5	0	20
11	17	33	35	28	26	25	13	9	17	20	0

4.1. Case 1
In this case, following problem parameters are considered $S = 30000$, $B = 0.5$, $W = 5000$, $V = 1000$, $G = 8000000$, $\tau = 30$, $L = 480$, $\delta = 0.05$, and the demand each customer equal to the number of population in each village (detail in Table 1). Initially, the number of route is set to 5. It is noted that the total available supply in the distribution center are enough to supply all customers demand.

The mixed integer linear programming proposed above is coded and solving using LINGO program. The result can be summarized in Table 3 and 4, with the objective function is equal to 0. Since the service time availability for each vehicle is 480 minutes, therefore, 2 vehicles are required for this case, in which the first vehicle is serving route 1 – 3 with 400 minutes total travel time and the second vehicle is serving route 4 – 5 with 271 minutes total travel time.
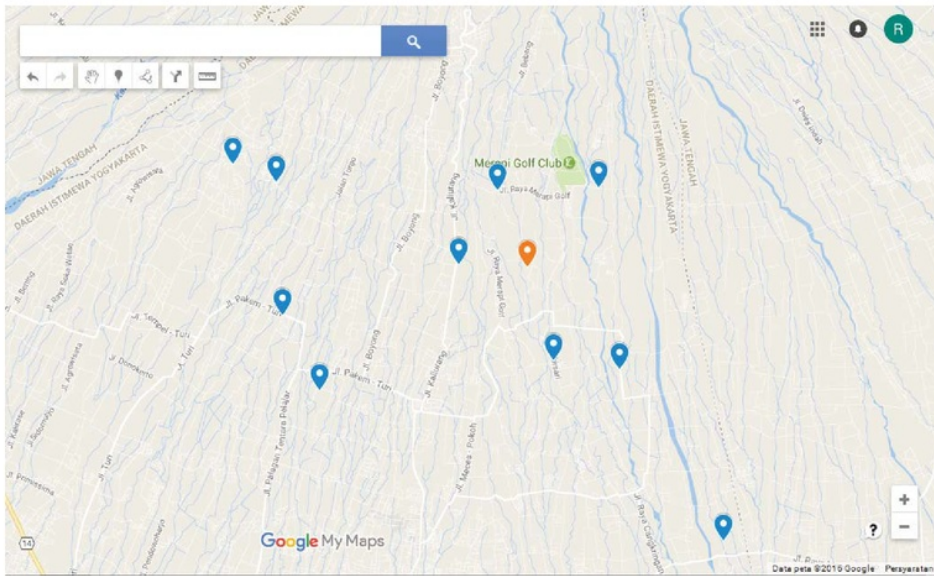
Figure 1. Locations of logistic distribution center (yellow) and customers (blue) in the Google Maps®

Table 3. Route formed for Case 1

No	Route	Total travel time
1	1-7-10-1	112
2	1-2-3-1	149
3	1-4-8-1	139
4	1-5-6-1	139
5	1-9-11-1	132

Table 4. Quantity of goods delivered and service level each customers in Case 1

Customer j	D_j	Q_j	F_j
2	946	946	1
3	590	590	1
4	814	814	1
5	580	580	1
6	3912	3912	1
7	1826	1826	1
8	4254	4254	1
9	7104	7104	1
10	2040	2040	1
11	599	599	1

4.2. Case 2

Case 1 and 2 are similar except the total supply, $S = 20000$. It is noted that the total available supply in the distribution center are not enough to supply all customers demand. Using the same software, the result from the model can be obtained and summarized in Table 5 and 6. It is noted that the objective function is equal to 2665. Since the service time availability for each vehicle is 480 minutes, therefore, 2 vehicles are required for this case, in which the first vehicle is serving route 1 – 3 with 436 minutes total travel time and the second vehicle is serving route 4 – 5 with 240 minutes total travel time. From Table 6, it is implied that the average of service level A is 0.9061 with minimum service level is 0.8561 and maximum service level is 0.9559.

Table 5. Route formed for Case 2

No	Route	Total travel time
1	1-10-4-1	136
2	1-5-2-1	147
3	1-3-6-1	153
4	1-7-8-1	108
5	1-11-9-1	132

Table 6. Quantity of goods delivered and service level each customers in Case 2

Customer j	D_j	Q_j	F_j
2	946	904	0.9556
3	590	564	0.9559
4	814	697	0.8563
5	580	554	0.9552
6	3912	3349	0.8561
7	1826	1745	0.9556
8	4254	3644	0.8566
9	7104	6090	0.8573
10	2040	1936	0.9490
11	599	517	0.8631

5. Conclusions

This paper presented a mathematical model that can be used in the case situated in KRB II region whenever Mount Merapi is erupted and affected KRB III. The proposed model is able to determine the location of distribution center, vehicle route, and the amount of goods delivered to each customer. Two different problem setting are considered in the numerical examples, in which both result show the capability of this model. In the future, several situations that actually happened in the KRB II during disaster need to be considered in the model, for example: reliability of the distribution center and uncertain demand in each location.

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