# MULTI-OBJECTIVE RELIEF DISTRIBUTION SYSTEM MODEL FOR VOLCANO DISASTER VICTIMS

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## ABSTRACT

Because of its location in the ring of fire, Indonesia has around 30% of all volcanoes in the world. After the volcano erupted, the area around the volcano was damaged and many people lost their houses, jobs, and possibilities to live in there. Before the volcano erupts, people who live around the volcano must be evacuated as soon as possible to one of the available shelters. In the shelters, drinking water, food, and medicine are needed by victims who were evacuated to survive aftermath of a disaster. To distribute reliefs to all shelters effectively, we developed a multi-objective relief distribution model. This distribution system model aims to determine the allocation of various types of relief items to several shelters with a minimum total cost and balanced service level between locations. This multi-objective relief distribution model considered multi-item, multi-period, multi-vehicle, and multi-trip by using a pre-emptive goal programming approach. This optimization model was applied to the numerical example based on Semeru Mount as the highest active volcanoes in Indonesia, which is located in Lumajang, East Java.

**Keywords**: relief distribution model, multi-objective optimization, pre-emptive goal programming

## 1. INTRODUCTION

Indonesia is an archipelago, located in the Pacific Ring of Fire and also in the meeting of four tectonic plates, i.e., the Asian continental plate, the Australian continental plate, the Indian Ocean plate, and the Pacific Ocean plate (CFE-DM, 2018). Because of its location, Indonesia geographically is a vulnerable country facing natural disasters (Van Rossum and Krukkert, 2010). Natural disasters, such as earthquakes, volcanic eruptions, and tornados, are catastrophic events caused by nature and cannot be controlled by men (Shaluf, 2007). In Indonesia, volcanic eruptions frequently occurred because Indonesia has around 30% of all volcanoes in the world. According to the Indonesian National Board for Disaster Management (BNPB), during the last 5 years, Indonesia has 78 volcanic eruptions; thus, this paper focuses on the impacts of volcano eruptions.

Natural disasters have caused damage and destruction of property, infrastructure, and assets; people lost their jobs and the possibilities to live (Sahay et al., 2016). To reduce or minimize the impact of natural disasters, a disaster management planning is needed. According to Perez-Gallarce (2017), the disaster management cycle contains four phases, namely, mitigation, preparedness, response, and recovery as shown in Figure 1. Habib (2016) categorized mitigation and preparedness into pre-disaster phases, whereas response and recovery phases are categorized into post-disaster phases. Mitigation phase is the first phase of disaster management that includes the activity steps to reduce vulnerability to disaster impacts, either economy or human (Camacho-Vallejo, 2015). Preparedness phase refers to design activities or procedures to minimize the disaster impacts to people and property. Response phase is a phase of aftermath disaster that includes all activities or operations to save lives and prevent further damage, whereas the recovery or reconstruction phase is a phase of aftermath disaster that includes rehabilitation activities (Altay and Green 2006).


**Figure 1**. Four phases of the Disaster Management Cycle
(Perez-Gallarce, 2017)

This paper focuses on the response phase of the disaster management cycle, a phase aftermath a volcanic eruption. Cozzolino (2012) divided the response phase into two sub-phases, namely, immediate response and restore, as shown in Figure 2. The immediate response sub-phase deals with how to rescue people, whereas the restore sub-phase deals with how to supply relief goods (medical attention, food, water, and shelter) to the refugees. Shaluf (2007) states that the worst consequence of volcanic eruption is when people have to be moved (evacuated) to shelters. Therefore, this paper deals on how to supply or distribute the relief goods to refugees in every shelter, especially to those who were affected by volcanic eruptions.

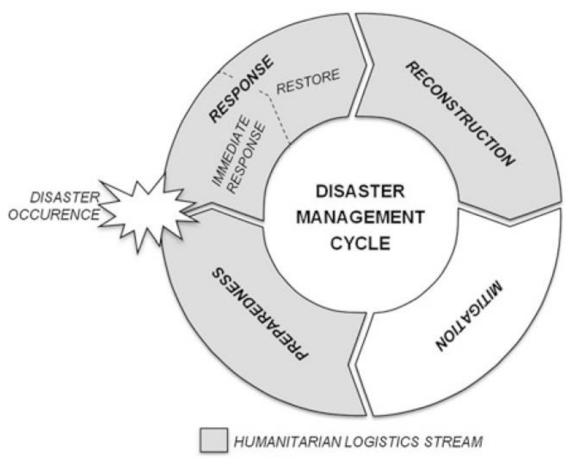


**Figure 2**. Response sub-phases in Disaster Management Cycle
(Cozzolino, 2012)

Each shelter needs various relief (multi-item) and regional and provincial agencies (BNPD) have to distribute multi-relief to multi-shelter using multi-vehicle. Each vehicle can have multi-trip per period to supply a similar or a different shelter. Therefore, this paper proposed a model of distributing multi-reliefs to multi-shelters using multi-vehicle, in which each vehicle can have many trips in a period. The proposed relief distribution system model has multi-objectives. The objectives are, first, to minimize the total cost of relief distribution and, second, to balance the service level of each shelter. Pre-emptive method is used to solve the multi-objective relief distribution system model. The pre-emptive methods solve the proposed model by completing each objective function in sequence (Winston, 2004).

## 2. RESEARCH FRAMEWORK

The research objectives can be achieved through systematic and structured steps. We started by defining the problem of distributing relief goods to each shelter. After the second step, which was to review literature, we began to develop the proposed model, which is a multi-objective distribution system model by considering multi-item, multi-vehicle, and multi-trip for each vehicle and multi-shelter. The next step was to create a scenario that consists of some actual data obtained in the field and some data assumptions. After completing the model using a pre-emptive approach and analyzing it, finally, conclusions and suggestions were done.

## 3. MODEL DEVELOPMENT

In the aftermath of a disaster, the basic needs of refugees must be met so the government through the BNPD distributes relief goods to each shelter where the refugees live. The proposed multi-objective distribution system model developed based on Lin et al. (2011) consists of two echelons, namely, the regional and provincial agency (BNPD) and multi-shelters. Regional and provincial agency (BNPD) is a government agency tasked to distribute the relief goods to multi-shelters. In each shelter, a lot of items are needed to be fulfilled during a certain period, and a corresponding penalty cost is imposed when the demand cannot be fulfilled within that period.

In the proposed distribution system model, one BNPD distributes relief items to many shelters. BNPD has multi-homogeneous vehicles to transfer multi-relief to shelters. In one period, vehicles can have many trips to the same or different shelter during a period as long as they have available time to transfer relief. At the same time (in one trip), a vehicle can only send multi-relief goods to one shelter, but the shelter can be visited by more than one vehicle that sends all requests for shelter in the same period. Each vehicle has weight and volume capacity restrictions. Certain relief demand at certain shelters in a period can be fulfilled by multiple vehicles and multiple trips using the same vehicle or not. This proposed model determined the number of reliefs that are distributed to a certain shelter using a certain vehicle in a certain trip at a certain period in order to minimize the total cost to meet the demand for relief goods and to minimize the gap in service level between shelters.

### 3.1. Mathematic Notation

Several mathematical notations that are used in this proposed multi-objective relief distribution system model can be classified become indexes, parameters, and decision variables as follows:

Index

$i$ = Type of relief
$j$ = Shelter location
$l$ = Vehicle
$t$ = Period
$k$ = trip

Parameter

$\xi_j$ = Transportation time to shelter location *j*
$C_{jl}$ = Transportation cost to location *j* using vehicle *l*
$H$ = Total of available work time per period
$W$ = Maximum load weight capacity of vehicle *l*
$V$ = Maximum load volume capacity of vehicle *l*
$M$ = A large number
$D_{ijt}$ = Demand of relief *i* at location *j* in period *t*
$FP_i$ = Penalty cost of relief *i* if there is remaining unsatisfied demand
$a_i$ = Unit weight of relief *i*
$b_i$ = Unit volume of relief *i*

Decision Variable
$X_{ijltk}$ = Amount of relief *i* delivered to shelter location *j* using vehicle *l* in period *t* trip *k*
$w_{ijt}$ = Unsatisfied demand for relief item *i* at shelter location *j* in period *t*
$S$ = Maximum difference of service level between two shelter locations
$s_j$ = Service level of shelter location *j*
$Y_{jltk}$ = Equal to 1 when relief are delivered to shelter location *j* using vehicle *l* at period *t* trip *k*, and 0 otherwise

### 3.2. Mathematic Formulation

This proposed aid distribution model has two objective functions. The first objective function (equation 1) is to minimize the total cost to meet the demand for relief goods, consisting of penalty cost and transportation cost. The penalty cost is the cost incurred because there is a demand for relief items that cannot be met. The second objective function (equation 2) is to minimize the gap of service level between shelters. This objective function aims to balance service level among shelters. Both objective functions are formulated as follows:

$$\min \sum_i \left( \left( \sum_j \sum_t D_{ijt} - \sum_j \sum_l \sum_t \sum_k X_{ijltk} \right) FP_i \right) + \sum_j \sum_l \sum_t \sum_k C_{jl} Y_{jltk} \tag{1}$$

$$min.\ S \tag{2}$$

This proposed model has several constraints as follows:

$$s_p - s_q = S^+ - S^- \quad \forall p, q \in \boldsymbol{J}, p \neq q \tag{3}$$

$$s_j = \frac{\sum_i \sum_l \sum_t \sum_k X_{ijltk}}{\sum_i \sum_t D_{ijt}} \qquad \forall j \tag{4}$$

$$\sum_l \sum_k (X_{ijltk} + w_{ijt}) = D_{ijt} \qquad \forall i, j, t \tag{5}$$

$$X_{ijltk} \leq M Y_{jltk} \qquad \forall i, j, l, t, k \tag{6}$$

$$\sum_j \sum_k \xi_j Y_{jltk} \leq H \qquad \forall l, t \tag{7}$$

$$\sum_i \sum_j a_i(X_{ijltk}) \leq W \qquad \forall l,t,k \tag{8}$$

$$\sum_i \sum_j b_i(X_{ijltk}) \leq V \qquad \forall l,t,k \tag{9}$$

$$\sum_j Y_{jltk} \leq 1 \qquad \forall l,t,k \tag{10}$$

$$Y_{ltk} = \sum_j Y_{jltk} \qquad \forall l,t,k \tag{11}$$

$$Y_{ltk} \geq Y_{jlt(k+1)} \qquad \forall l,t,k; k < \bar{k} \tag{12}$$

$$S^+, S^- \geq 0 \tag{13}$$

$$S^+, S^- \leq S \tag{14}$$

$$w_{ijt} \geq 0 \qquad \forall i,j,t \tag{15}$$

$$X_{ijltk} \geq 0 \qquad \forall i,j,l,t,k \tag{16}$$

$$Y_{jltk} \in \{0,1\} \qquad \forall j,l,t,k \tag{17}$$

Equations (3) and (4) are used to determine the gap in service levels to meet the needs of all relief items at the shelter. The level of service for fulfilling all relief items at the shelter is calculated from the ratio between the total demand for all relief goods that are fulfilled at the shelter and the total demand for all relief goods at the shelter. Equation (5) ensures that the total demand for each item of relief goods in a period is fulfilled within that period. Equation (6) guarantees that the relief goods are delivered using the assigned vehicle, whereas equation (7) ensures that in each period, each vehicle can be used only in the available working hours in that period. Equations (8) and (9) limit the total weight and total volume of loading of relief goods to not exceed the capacity of the vehicle. Equations (10) and (11) ensure that each vehicle on the same trip only sends relief goods to one shelter, whereas equation (12) guarantee that all trips of each vehicle are done in sequence order. Equations (13) and (14) guarantee that the values of the gap are absolute. Equations (15) and (16) guarantee non-negative decision variables, whereas equation (17) ensures binary decision variables.

## 4. RESULTS & DISCUSSION

The proposed multi-objective distribution system model is implemented using Mount Semeru data. Mount Semeru is one of the most active volcanoes in East Java, Indonesia, exactly located in Lumajang city. The height of Mount Semeru is 3,676 m above sea level, making it the highest mount in East Java. In the aftermath of a disaster, relief goods are distributed to the victims. Distributed relief goods have to be suitable for their needs. Mount Semeru data can be obtained from BPBD Lumajang. All data are collected as shown in Table 1. - Table 4.

**Table 1.** Shelter Location and Number of Refugee

| Location | Capacity (person) | Number of Refugee (person) | Breastfeeding mothers (person) | Toddler (kid) |
|---|---|---|---|---|
| GOR Wira Bakti & Lapangan | 20,000 | 18,413 | 3,995 | 1,149 |

| Location | Capacity (person) | Number of Refugee (person) | Breastfeeding mothers (person) | Toddler (kid) |
|---|---|---|---|---|
| Stadion Semeru | 30,000 | 29,642 | 5,640 | 1,209 |
| Barak/Aula Yonif 527 | 7,500 | 6,826 | 700 | - |
| Asrama Nakertrans | 1,000 | 808 | 428 | 272 |
| Kantor Diklat | 1,000 | 809 | 429 | 273 |
| **Total** | **59,500** | **56,498** | **11,192** | **2,903** |

**Table 2.** Amount of Relief Sent For Each Location Each Period

| Relief goods | Dimension | Location of shelter | | | | |
|---|---|---|---|---|---|---|
| | | GOR Wira Bakti & Lapangan | Stadion Semeru | Barak/Aula Yonif 527 | Asrama Nakertrans | Kantor Diklat |
| Mineral water 600 ml | box | 2,878 | 4,739 | 1,423 | 90 | 90 |
| Prepared food | box | 864 | 1,422 | 342 | 27 | 27 |
| Medicine | box | 185 | 297 | 68 | 8 | 8 |
| Toddler food | pack | 575 | 605 | - | 136 | 137 |
| Sanitary napkins | pack | 160 | 226 | 28 | 18 | 18 |

**Table 3**. Weight, Volume and Penalty Cost of Each Relief

| Relief good<br>1 | Weight (kg)<br>2 | Volume ($m^3$)<br>3 | Penalty cost (Rp)<br>4 |
|---|---|---|---|
| Mineral water 600 ml | 15 | 0.0239 | 1,500,000,- |
| Prepared food | 3 | 0.0217 | 1,500,000,- |
| Medicine | 5 | 0.006 | 1,500,000,- |
| Toddler food | 0.12 | 0.0008 | 1,500,000,- |
| Sanitary napkins | 1.5 | 0.0078 | 1,500,000,- |

**Table 4**. Parameters

| Parameter<br>1 | Amount<br>2 |
|---|---|
| Number of vehicle | 3 units |
| Weight capacity of vehicle | 5,895 kg |
| Volume capacity of vehicle | 13 $m^3$ |
| Travel time to each shelter location | 0,5 hour |
| Loading and unloading time of relief | 1 hour |
| Number of trips | 6 trips |
| Operation time | 10 hours |
| Planning periods | 7 days |

Using a pre-emptive approach, relief goods sent to the shelter location can be shown in Table 5 and the unfulfilled demand can be shown in Table 6.

**Table 5.** Number of Relief Goods Sent

| Relief | Shelter Location | Period | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Mineral water 600 ml | GOR Wira Bakti & Lapangan | 1709.93 | 1709.93 | 1709.93 | 1709.93 | 1273.36 | 2102.93 | 1709.93 |
| | Stadion | 3126.1 | 2340.1 | 3126.1 | 2910.7 | 3126.16 | 2565.4 | 3126.16 |

| Relief | Shelter Location | Period | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | Semeru | 6 | 6 | 6 | 4 | | 8 | |
| | Barak/Aula Yonif 527 | 692.13 | 1423 | 108.13 | 692.13 | 1423 | 692.13 | 672.15 |
| | Asrama Nakertrans | 0 | 90 | 90 | 0 | 0 | 57.071 | 90 |
| | Kantor Diklat | 90 | 90 | 0 | 90 | 90 | 0 | 90 |
| Prepared food | GOR Wira Bakti & Lapangan | 864 | 864 | 864 | 864 | 864 | 864 | 864 |
| | Stadion Semeru | 1422 | 1422 | 1422 | 1422 | 1422 | 1422 | 1422 |
| | Barak/Aula Yonif 527 | 342 | 342 | 342 | 342 | 342 | 342 | 342 |
| | Asrama Nakertrans | 27 | 27 | 27 | 27 | 0 | 27 | 27 |
| | Kantor Diklat | 27 | 27 | 0 | 27 | 27 | 27 | 27 |
| Medicine | GOR Wira Bakti & Lapangan | 185 | 185 | 185 | 185 | 185 | 185 | 185 |
| | Stadion Semeru | 297 | 297 | 297 | 297 | 297 | 297 | 297 |
| | Barak/Aula Yonif 527 | 68 | 68 | 68 | 68 | 68 | 68 | 68 |
| | Asrama Nakertrans | 8 | 8 | 8 | 8 | 0 | 8 | 8 |
| | Kantor Diklat | 0 | 8 | 0 | 0 | 0 | 8 | 0 |
| Toddler food | GOR Wira Bakti & Lapangan | 575 | 575 | 575 | 575 | 575 | 575 | 575 |
| | Stadion Semeru | 605 | 605 | 605 | 605 | 605 | 605 | 605 |
| | Barak/Aula Yonif 527 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Asrama Nakertrans | 136 | 136 | 136 | 136 | 0 | 136 | 136 |
| | Kantor Diklat | 137 | 99,30361 | 0 | 137 | 137 | 137 | 137 |
| Sanitary napkins | GOR Wira Bakti & Lapangan | 160 | 160 | 160 | 160 | 160 | 160 | 160 |
| | Stadion Semeru | 226 | 226 | 226 | 226 | 226 | 226 | 226 |
| | Barak/Aula Yonif 527 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| | Asrama Nakertrans | 18 | 18 | 18 | 18 | 0 | 18 | 18 |
| | Kantor Diklat | 0 | 0 | 0 | 18 | 0 | 18 | 18 |

**Table 6.** Unfulfilled Demand

| Relief | Shelter Location | Period | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Mineral water 600 ml | GOR Wira Bakti & Lapangan | 1168.067 | 1168.067 | 1168.067 | 1168.067 | 1604.645 | 775.0667 | 1168.067 |
| | Stadion Semeru | 1612.84 | 2398.84 | 1612.84 | 1828.26 | 1612.84 | 2173.515 | 1612.84 |
| | Barak/Aula Yonif 527 | 730.86 | 0 | 337.87 | 730.87 | 0 | 730.87 | 750.85 |
| | Asrama Nakertrans | 90 | 0 | 0 | 90 | 90 | 32.93 | 0 |
| | Kantor Diklat | 0 | 0 | 90 | 0 | 0 | 90 | 0 |
| Prepared food | GOR Wira Bakti & Lapangan | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Stadion Semeru | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Barak/Aula Yonif 527 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Asrama Nakertrans | 0 | 0 | 0 | 0 | 27 | 0 | 0 |
| | Kantor Diklat | 0 | 0 | 27 | 0 | 0 | 0 | 0 |
| Medicine | GOR Wira Bakti & Lapangan | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Stadion Semeru | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Barak/Aula Yonif 527 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Asrama Nakertrans | 0 | 0 | 0 | 0 | 8 | 0 | 0 |
| | Kantor Diklat | 8 | 0 | 8 | 8 | 8 | 0 | 8 |
| Toddler food | GOR Wira Bakti & Lapangan | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Stadion Semeru | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Barak/Aula Yonif 527 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Asrama Nakertrans | 0 | 0 | 0 | 0 | 136 | 0 | 0 |
| | Kantor Diklat | 0 | 37.69 | 137 | 0 | 0 | 0 | 0 |
| Sanitary napkins | GOR Wira Bakti & Lapangan | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Stadion Semeru | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Barak/Aula Yonif 527 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Asrama | 0 | 0 | 0 | 0 | 18 | 0 | 0 |

| Relief | Shelter Location | Period | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | Nakertrans | | | | | | | |
| | Kantor Diklat | 18 | 18 | 18 | 0 | 18 | 0 | 0 |

Table 7 shows the level of service for each number of shelters 0.74811. This value recognizes the percentage of fulfillment of 74,811% of the total shelter demand. In addition, the percentage of fulfillment of each demand is the same, and this means that each shelter is served equally. The results of model gave the first objective function, the total cost amount Rp.38,009,100 and the second objective function is no gap of service level between all shelter locations.

Table 7. Service Level of each Shelter

| Shelter Location | Service Level |
|---|---|
| GOR Wira Bakti & Lapangan | 0,74811 |
| Stadion Semeru | 0,74811 |
| Barak/Aula Yonif 527 | 0,74811 |
| Asrama Nakertrans | 0,74811 |
| Kantor Diklat | 0,74811 |

## 5. CONCLUSION

During the restore sub-phase, BNPD distributes multi-reliefs to multi-shelters using multi-vehicles which each vehicle has multi-trips. The proposed relief distribution model gave result with minimal cost as well as balanced service level. The future research should develop metaheuristic algorithm in order to solve the proposed model faster.

## 6. ACKNOWLEDGEMENT

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