

OR/MS Applications in Mt. Merapi Disaster Management

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Abstract: Problem statement: Much of researches on the management of disaster deal with their social aspects such as sociological and psychological effects on communities. Recently there had been a growing credit of the demand for application of the operational research and management science matters in disaster management. This approach commonly utilizes decision theory, dynamical system and optimization technique to minimize the cost and recovery time. **Approach:** In this study we provide a comprehensive resource allocation model for disaster management, which consists of logistics distribution and humanitarian aid workforce's assignment problems. The former was formulated in the form of integer linear programming whose objective was to minimize the logistic demand shortage. While the later was framed into goal programming basis to minimize penalty cost. **Results:** We implement our models in Mt. Merapi disaster operation activities. We first carry out the problem of logistic distribution between affected areas and distribution centers in the city basis. We then organize the assignment of humanitarian workforces in disaster response and recovery actions. Workers from several volunteer communities were assigned regarding their preferences on task and time. **Conclusion:** Approaches by Operations Research and Management Science (OR/MS) not only efficiently and optimally solve the problem of logistic distribution and humanitarian assignment in accelerating disaster responses and recovery processes, but also offer flexibilities in dealing with the problem. In application, the scale of the problem can easily be extended.

Key words: Operations Research and Management Science (OR/MS), Decision Support Systems (DSS), Board for Disaster Management of Indonesia (BNPB), Mt. Merapi

INTRODUCTION

Natural disasters come in many forms such as earthquakes, volcano eruptions, floods, fires and others. Some of them are catastrophe and have displaced a million people from their homes around the world each decade, a million more were dead and many needed rescuing. This number is expected to increase as populations densities rise and more people are forced to live in disaster prone areas. Beyond that, economically, physical and psychological damages are other tragic impacts of disasters. To minimize the damages caused by disasters, various efforts have been carried out by government, local, regional and international communities including donor agencies. A lot of funds have been devoted during the disaster response and recovery phases. However, some responses undertaken by government are poor, questioning of what went wrong such that emergency management agencies performed so ineffectively and suggesting on the importance of Operations Research and Management Science (OR/MS) in preparedness and response activities (Sylves, 2008; Ozlem *et al.*, 2011).

Many researches in the field of disaster management focus in social aspects of disaster (Hughes, 1991). However, recently there has been a growing attention on the utilization of OR/MS in disaster management to minimize loss or cost functions as well as response and recovery periods. Altay and Green (2006) conduct a comprehensive literature survey of the existing OR/MS studies.

To be more specific, Odzamar *et al.* (2004) develop a logistics planning model which integrated into a natural disaster logistics DSS. A hybrid model of logistics disaster management by integrating multi-commodity network flow model and vehicle routing problem is proposed, while Rolland *et al.* (2010) propose a Decision Support System (DSS) for disaster response and recovery using hybrid meta-heuristics. Matisziw *et al.* (2010) introduce a multi-objective optimization model for network restoration during disaster recovery, which permits tradeoffs between the two objectives, minimization of the system cost and maximization of system flow. A stochastic optimization model for the storage and distribution problem of

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medical supplies to be used for disaster management under a wide variety of possible disaster types and magnitudes is proposed by Mete and Zabinsky (2010). A recent article on how operations research tools can be used to make better decisions and discuss potential general research directions in disaster management is (Ergun *et al.*, 2010). Schryen and Wex (2012) exploit the experience of design research in information systems to produce high-level design knowledge and to derive implications for future research in a key area of natural disaster management. Research in the field of humanitarian relief is also intensive. Falasca and Zobel (2011) present a two-stage stochastic decision model with recourse for procurement in humanitarian relief supply chains, which captures and models both the procurement process and the uncertainty inherent in a disaster relief situation. A study on humanitarian workers' assignment problems in emergency response is done by Falasca *et al.* (2009). While, Falasca *et al.* (2011) discuss the development of a spreadsheet-based multi-criteria volunteer scheduling model for a small development organization in the South American country. The model proposed in this study can reduce the number of unfilled shifts, decrease total scheduling costs and maximize satisfied volunteers' preferences. For an extensive reference, readers may consult the 2011 Special Issue on Humanitarian Applications of Interfaces journal.

In Indonesia, during 2011 more than 1500 disasters, both natural and human-made, are occurring, with fires and floods are the most. Funds amounting to IDR 4 trillion had been disbursed by government to respond disasters. After the 2004 Indian Ocean Tsunami which hit Aceh and killed a hundred thousand people and the 2009 West Sumatra earthquakes which killed more than 6000, the last catastrophic disaster in Indonesia was the eruption of Mt. Merapi in October-November 2010. Mt. Merapi, 2968 m, located in the heart of the island of Java, is the most active volcano in Indonesia. Erupted every 2 to 5 years, Mt. Merapi is surrounded by dense settlements. Nearest cities such as Yogyakarta and Magelang are just in the radius of 30 km from the Merapi's peak. Moreover, there still exists settlement even at an altitude of 1700 meters within 4 km from the peak. According to the National Board for Disaster Management of Indonesia (BNPB), the 2010 eruptions attacked 7 regions in 2 provinces, caused 386 deaths, most from burns and suffocation and more than 270 thousand displaced.

In the case of Merapi, there are at least two major emergency response activities: distribution of relief goods and assignment of humanitarian aid workforces. Both activities are performed and partly organized by many parties such as government agencies, Red Cross, TV

and news stations and community groups. As commonly occurred when disaster strikes, Merapi emergency response activities are spontaneous, uncoordinated, occur concurrently and, on occasion, overlap or conflict with one another. To the best of our knowledge, OR/OM approaches were not adequately utilized.

In this work we study the implementation of OR/MS in disaster management of Mt. Merapi. The primary task of this study is two-fold. First we employ a multicommodity and multi-modal transportation model in distributing relief goods. Second we carry out an assignment model in organizing humanitarian aid workforce deployment.

MATERIALS AND METHODS

Materials exploit in this studies are logistics distribution model which formulated in mixed integer programming and humanitarian aid workforces assignment model which expressed in goal programming.

Logistics distribution problem: The problem of logistics distribution in disaster management commonly involves inter-regional transportation of relief goods such as medical aid materials, food and specialized equipment, where the quantities, origins, destinations and vehicles to be dispatched are decided by coordination center. In this case, vehicles are not necessary to return to the center; rather they wait at their last stop until receiving the next order from the center. During an emergency response, demand and supply of relief goods are changing time to time. Level of demand is usually known for the initial period, but the future level should be forecasted. Supply is more limited but prospective supply arrivals usually know in advance. It means that the plan should be regularly updated to gain new information on demands, supplies and vehicle availability, i.e., A time-dependent logistics distribution model which incorporates multicommodity and multi-modal is needed.

Given the characteristics mentioned above, we here adopt the logistics distribution model proposed by (Odzamar *et al.*, 2004). The following is the simplified mathematical formulation.

Data sets and indices: We define by $T = [0; T]$ the planning period, where T is the planning time horizon, by $\mathbb{N} = \{1, 2, \dots, N\}$ the set of all nodes or areas, by $\mathbb{M} = \{1, 2, \dots, M\}$ the set of all transportation modes, by $\mathbb{V}_m = \{1, 2, \dots, V_m\}$ the set of vehicle types defined for each transportation mode m , by D and S the set of demand and supply nodes, respectively. It is clear that

$D \subset \mathbb{N}$ and $S \subset \mathbb{N}$. The set of all commodities is denoted by $C = \{1, 2, \dots, C\}$. Indices are introduced as follows: $i \in C, j, k \in \mathbb{N}, l \in V_m$ and $m \in M$.

Parameters: We define by d_{ijt} the amount of commodity i demanded or supplied by node j at time t . If $d_{ijt} \geq 0$ then it represents a supply, otherwise a demand. We denote by n_{jlmt} the number of vehicle type l of mode m at node j added to the fleet at time t , by w_i the unit weight of commodity i and by K_{lm} the load capacity of vehicle type l of mode m . The frequencies of commodity delivery are denoted by f_{jklm} , where in a period there is at most one delivery. That whose delivery is more than one in a period is denoted by g_{jklm} . If there is no link between nodes j and k , then $f = g = 0$.

Decision variables: We define by X_{ijkmt} the amount of commodity i traversing arc (j, k) using transportation mode m at time t , by \bar{X}_{ijkmt} the amount of suspended commodity, by δ_{ijt} the amount of unsatisfied demand of commodity i at node j at time t , by Y_{jklmt} the number of vehicles of type l of mode m traversing arc (j, k) at time t and by \bar{Y}_{jklmt} the number of adjourned vehicles at node j .

Objective function: Different from standard vehicle routing problem where supply is assumed to be abundant, in disaster situation supply is available in limited quantities and its availability varies over time during the period and, oppositely, the demand level is higher. Thus, the objective of the model is to minimize the sum of unsatisfied demand for all commodities throughout the planning period, i.e., Eq. 1:

$$\min \delta := \sum_{i \in C} \sum_{j \in D} \sum_{t \in T} \delta_{ijt} \quad (1)$$

Constraints: The following constraints, which consist of linear and integer parts, must be satisfied in achieving (1).

- Material flow on demand nodes and transshipment nodes has to be balanced after counting the quantity of unsatisfied demand. That is Eq. 2:

$$\sum_{l \in V_m} \sum_{m \in M} \sum_{k \in \mathbb{N}} (X_{ijkmt} - \bar{X}_{ijkmt}) = \delta_{ijt} + d_{ijt} \quad (2)$$

for all $i \in C, j \in D$ and $t \in T$.

- Material flow on demand nodes and supply nodes has to be balanced, i.e., supply quantity should not exceed the demand quantity Eq. 3:

$$\sum_{l \in V_m} \sum_{m \in M} \sum_{k \in \mathbb{N}} (X_{ijkmt} - \bar{X}_{ijkmt}) \leq d_{ijt} \quad (3)$$

for all $i \in C, j \in D$ and $t \in T$.

- The amount of traversing commodity should obey the capacity of vehicle Eq. 4 and 5:

$$\sum_{i \in C} w_i X_{ijkmt} \leq \sum_{l \in V_m} Y_{jklmt} K_{lm} f_{jklm} \quad (4)$$

$$\sum_{i \in C} w_i X_{ijkmt} \leq \sum_{l \in V_m} W_{jklmt} K_{lm} g_{jklm} \quad (5)$$

for all, $j, k \in C, N, m \in M$ and $t \in T$.

- The number of arriving vehicles at node j should be equal to the number of adjourned and dispatched vehicles from that node Eq. 6:

$$\sum_{k \in \mathbb{N}} (Y_{jklmt} + \bar{Y}_{jklmt}) = \sum_{k \in \mathbb{N}} Y_{kjlmt} \quad (6)$$

for all $l \in V_m, m \in M$ and $t \in T$.

- The number of dispatch vehicles is not exceeding its availability over time Eq. 7:

$$\sum_{k \in \mathbb{N}} (Y_{jklmt} + \bar{Y}_{jklmt}) \leq n_{jlmt} \quad (7)$$

for all $l \in V_m, m \in M$ and $t \in T$.

- Some variables are non-negative and/or integer:

$$Y_{jklmt}, \bar{Y}_{jklmt} \in \mathbb{Z}^+ \cup \{0\}, X_{ijkmt}, \bar{X}_{ijkmt} \geq 0$$

$$\text{and } \delta_{ijt} \geq 0$$

Note that model with constraints (2)-(3) is a linear programming problem and that with (4)-(7) is an integer problem. Complete description of the model including logic and assumption can be found in (Odzamar *et al.*, 2004).

Humanitarian aid workforce's assignment problem:

The assignment problem of humanitarian aid workers, i.e., volunteers, possesses intrinsic fundamental uniqueness compared to traditional labor assignment (Sampson, 2006). While the later sets the labor variable

cost, volunteer labor assignment neglects such a cost. Volunteer labor assignment takes a possible advantage of using more labor than minimized it, however, the availability of committed labor is finite and may not cover task demand. Thus, in the framework of optimization modeling, it is suggested to maximize task accomplishment by minimizing shortages which should be balanced among tasks as the objective function with respect to volunteers' preferences on time and task (Falasca *et al.*, 2009).

In this work we partly adopt models described in (Sampson, 2006), (Falasca *et al.*, 2009) and (Kaspari, 2010). For organizational reasons, we classify volunteers according to their community groups since community based disaster response is an important local asset as in a large-scale disaster, more and more resources will be needed (Schneid and Collins, 2001; Jahangiri *et al.* 2011). All set, indices, parameters and variables involved in the model are provided as follows.

Data sets and indices: We define by $I = \{1, 2, \dots, N\}$ the set of all volunteer groups, by $J_i = \{1, 2, \dots, \}$ the set of all volunteers in the i -th group, by $K = \{1, 2, \dots, K\}$ the set of all time blocks or shifts and by $L = \{1, 2, \dots, L\}$ the set of all tasks. Indices are given as follows: $i \in I, j \in J_i, k \in K$ and $l \in L$.

Parameters: Parameters involved in the model are classified as those determined by volunteers and those decided by the volunteer coordinator. We define by 1 if volunteer j of group i is available at shift k , otherwise $a_{ijk} = 0$. We define by $\beta_{ijl} = 1$ if volunteer j of group i has a skill to accomplish task l , otherwise $\beta_{ijl} = 0$. To accommodate the volunteers' time and task preferences, we define by τ_{ij}^+, τ_{ij}^- and τ_{ij} the number of shifts wished by volunteer i of group j , its acceptable excess and its acceptable shortage, respectively. The first parameter is called as aspiration level. The following parameters are all decided by the coordinator. We denote by ω_{ij} the required number of shifts should be assigned to volunteer j of group i , i.e., the ideal level. We denote also by $\mu_{kl}, \mu_{kl}^+, \mu_{kl}^-$ the required number of volunteers should be assigned at shift k to accomplish task l , its allowable excess and its allowable shortage, respectively.

Variables: While parameters are symbolized by Greek characters, we use Roman characters for variables. The following are all deviations variables. We define by u_{kl}^+ and u_{kl}^- the excess and shortage of volunteers assigned at shift k to complete task l , respectively, by

t_{ij}^+ and t_{ij}^- the excess and shortage of shifts assigned to volunteer i of group j in accordance with his/her time preferences, respectively and by w_{ij}^+ and w_{ij}^- the excess and shortage of shifts assigned to volunteer i of group j in accordance with coordinator's requirements, respectively.

Decision variables: The primary decision variable is denoted by binary variable $x_{ijkl} = 1$ if volunteer i of group j is assigned to shift k to accomplish task l and $x_{ijkl} = 0$ otherwise. We also define the following dummy decision variable to activate some constraints: $y_{ij} = 1$ if volunteer i of group j is assigned at any shift to accomplish any task and $y_{ij} = 0$ otherwise.

Objective function: Our humanitarian aid workers' assignment problem is formulated as a goal programming model with binary and integer variables. The objective function of this model is to minimize penalty costs incurred by deviating on the number of volunteers, shifts and tasks from their aspiration and ideal levels. We aim to Eq. 8:

$$\min_{x_{ijkl}} z := \sum_{i=1}^6 z_i \tag{8}$$

where, $z_1 := \sum_{k,l} \rho_{kl}^1 u_{kl}^-$ and $z_2 := \sum_{k,l} \rho_{kl}^2 u_{kl}^+$ represent penalty costs due to (negative and positive) deviations on the number of volunteers assigned at shift k to complete task l from ideal levels, respectively, $z_3 := \sum_{i,j} \rho_{ij}^3 t_{ij}^-$ and $z_4 := \sum_{i,j} \rho_{ij}^4 t_{ij}^+$ represent penalty costs due to deviations on the number of shifts assigned to volunteers j of group i from aspiration levels, respectively and $z_5 := \sum_{i,j} \rho_{ij}^5 w_{ij}^-$ and $z_6 := \sum_{i,j} \rho_{ij}^6 w_{ij}^+$ represent penalty costs due to deviations on the number of shifts assigned to volunteers j of group i from ideal levels, respectively. Here, ρ^n ($n = 1, 2, \dots, 6$) corresponds to unit penalty costs which can be determined according to their importance degrees.

Constraints: We have to achieve (8) with respect to the following constraints:

- Volunteer j of group i accomplishes at most one task at each wished time block, i.e., Eq. 9:

$$\sum_{l \in L} x_{ijkl} \leq \alpha_{ijk} \tag{9}$$

for all $i \in I, j \in J_i$ and $k \in K$.

- Volunteer j of group i should have an appropriate skill to complete task l . We write Eq. 10:

$$x_{ijkl} \leq \beta_{ij} \tag{10}$$

for all $i \in I, j \in J_i, k \in K$ and $l \in L$.

- In order x_{ijkl} and y_{ij} have correct values, the following must be satisfied Eq. 11:

$$x_{ijkl} \leq y_{ij} \tag{11}$$

for all $i \in I, j \in J_i, k \in K$ and $l \in L$.

- It is required that there is a number of μ_{kl} volunteers at shift k to complete task l Eq. 12:

$$\sum_{i \in I} \sum_{j \in J_i} x_{ijkl} + u_{kl}^- + u_{kl}^+ = \mu_{kl} \tag{12}$$

for all $k \in K$ and $l \in L$.

- Volunteer j of group i is required by coordinator to accomplish a number of ω_{ij} tasks during the period. That is Eq. 13:

$$\sum_{k \in K} \sum_{l \in L} x_{ijkl} + w_{ij}^- + w_{ij}^+ = y_{ij} \omega_{ij} \tag{13}$$

for all $i \in I$ and $j \in J_i$.

- Volunteer j of group i prefer to work on τ_{ij} shifts during the period. That is Eq. 14:

$$\sum_{k \in K} \sum_{l \in L} x_{ijkl} + t_{ij}^+ + t_{ij}^- = y_{ij} \tau_{ij} \tag{14}$$

for all $i \in I$ and $j \in J_i$.

- The volunteer shortage and excess which represented by deviation variables should not be out-of-range from their aspiration and ideal bounds. Since $\mu_{kl} - \mu_{kl}^- \leq \mu_{kl} \leq \mu_{kl} + \mu_{kl}^+$ then Eq. 15:

$$u_{kl}^- \leq \mu_{kl}^-, u_{kl}^+ \leq \mu_{kl}^+ \tag{15}$$

For all $k \in K$ and $l \in L$. And since $\tau_{ij} - \tau_{ij}^- \leq \tau_{ij} \leq \tau_{ij} + \tau_{ij}^+$ then Eq. 16:

$$t_{ij}^+ \leq \tau_{ij}^-, t_{ij}^- \leq \tau_{ij}^+ \tag{16}$$

for all $i \in I$ and $j \in J_i$. Constraints (15) and (16) ensure that requirements asked by the coordinator and preferences desired by volunteers are satisfied.

- Deviation variables are all non-negative integers Eq. 17:

$$u_{kl}^-, u_{kl}^+, w_{ij}^-, w_{ij}^+, t_{ij}^-, t_{ij}^+ \in \mathbb{Z}^+ \cup \{0\} \tag{17}$$

For all $i \in I, j \in J_i, k \in K$ and $l \in L$.

The above model, however, requires coordinator to cleverly determine the ideal levels according to the number of volunteers and the number of shifts burdened to a volunteer. The coordinator must try to make sure that there are a sufficient number of volunteers at all time blocks while taking into account individual time and shift preferences in such a way that volunteers are all fairly considered (Falasca *et al.*, 2009). In some cases, it has happened that the model is not feasible due to the volunteer scarcity. As noticed by Kaspari (2010), a two-phase approach can undertake the situation. We first introduce a non-negative variable s_{ikl} as the number of volunteer scarcity in group i assigned at shift k to complete task l . Constraint (12) is then replaced by Eq. 18:

$$\sum_{i \in I} \sum_{j \in J_i} x_{ijkl} + s_{ikl} + u_{kl}^- + u_{kl}^+ = \mu_{kl} \tag{18}$$

The initial phase of optimization is therefore minimized the number of volunteer scarcity Eq. 19:

$$\min s := \sum_{i,k,l} s_{ikl} \tag{19}$$

If the modified model is solved and $s = 0$ then the problem is feasible and the original problem can also be carried out. Otherwise, the coordinator must ask additional volunteers from each group or adjust some constraints or parameters. We shall implement this approach in model applications.

RESULTS

Now we present the result of model implementation. Firstly we describe the application of logistics distribution model in Mt. Merapi disaster logistic operation. Secondly we illustrate the implementation of humanitarian aid worker assignment model.

Logistics distribution model: For implementation of the model, we consider logistics distribution among six regions as nodes.

Magelang, Sleman and Yogyakarta represent the affected areas, i.e., demand nodes, Kulonprogo, Bantul and Solo act for supply nodes. We only consider two relief goods: food and medical aid material. One unit of food is equivalent to, let say 300 kg of food and one unit of medical aid material is equivalent to 200 kilograms. It is assumed that the planning time horizon is 5 days. The estimation of demand and supply quantities within 5 days is provided in Table 1.

Table 1: Estimation of demand and supply quantities of relief goods (unit)

Goods	Region	Day				
		1	2	3	4	5
Foods	Magelang	-100	-200	-100	-100	-100
	Sleman	-400	-400	-350	-300	-300
	Yogyakarta	-100	-150	-150	-200	-200
	Kulonprogo	200	200	250	300	250
	Solo	150	200	100	100	200
Medical	Bantul	300	250	200	200	250
	Magelang	-250	-175	-200	-200	-200
	Sleman	-250	-200	-200	-150	-100
	Yogyakarta	-100	-125	-150	-200	-100
	Kulonprogo	100	200	150	150	150
	Solo	150	200	200	200	150
	Bantul	200	200	200	250	100

Table 2: Vehicles availability and capacity (unit)

Region	Trailer	Truck	Wagon	Train
Magelang	5	5	10	0
Sleman	0	0	0	0
Yogyakarta	5	5	5	0
Kulonprogo	10	15	20	1
Solo	5	10	15	1
Bantul	10	10	10	1
Capacity	150	75	25	200

Table 3: Demand-supply accumulation

Region	Region End of day 1		Begin of day 2	
	Food	Medical	Food	Medical
Magelang	0	-25	-200	-200
Sleman	0	-25	-400	-225
Yogyakarta	0	-100	-150	-225
Kulonprogo	0	0	200	200
Solo	47	0	247	200
Bantul	3	0	253	200

We assume only two transportation modes available: ground and railways. The number of available vehicles in each area is assumed constant day-by-day, see Table 2. The transportation network between regions is given by Fig. 1. Ground and railway modes are, respectively, denoted by solid and dashed paths. Ground mode has three types of vehicle: trailer, truck and wagon. The frequencies of commodity delivery are set by $f_{jklm} = 1$ provided there is a link and $g_{jklm} = 2$ for Magelang-Kulonprogo by truck and Magelang-Kulonprogo, Magelang-Solo, Sleman-Kulonprogo by wagon. In this case, truck and wagon can transport relief goods twice a day.

Model is then executed to perform relief goods distribution among regions. Distribution and transportation schedules in fulfilling demand in the first day, which given in the third column of Table 1, is illustrated in Fig. 2. It can be shown that, in the first period, a coordination center in Kulonprogo, which stocked 200 units of food and 100 units of medical aid material, conveys 100 units of food by using 2 trucks to Magelang, which suffered from 200 units of food and 100 units of medical aid material.

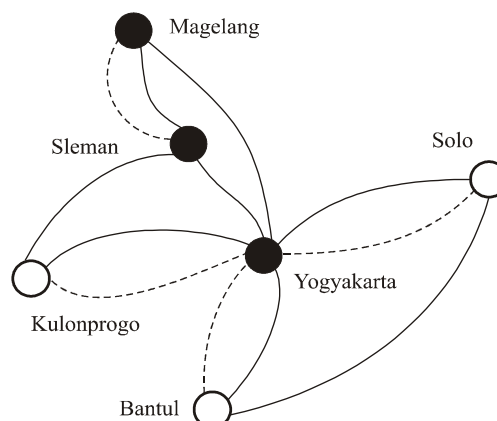


Fig. 1: Transportation network

Table 4: Unsatisfied demand after 5 periods (unit)

Day	Region	Unsatisfied demand	
		Food	Medical
1	Magelang	0	25
	Sleman	0	25
	Yogyakarta	0	100
2	Magelang	0	0
	Sleman	50	50
	Yogyakarta	0	0
3	Magelang	0	0
	Sleman	50	50
	Yogyakarta	0	0
4	Magelang	32	0
	Sleman	18	0
	Yogyakarta	0	0
5	Magelang	0	0
	Sleman	0	0
	Yogyakarta	0	0

Table 5: The number of committed volunteers

Group	Number of volunteers	
	Phase I	Phase II
Pareanom	7	10
JME	6	8
Jalin Merapi	7	12
MLR	8	10
Balerante	5	9
Turgosari	9	11
Total	42	60

At the same time, Kulonprogo transports all remaining stocks to Sleman by using 2 trailers and 1 train. While, Magelang also receives 225 units of medical aid material supplied by Bantul. In fact, it is not necessary to deliver the aid directly from the supply center to affected areas. Indirect transport is also possible as we convey 25 units of medical aid from Solo to Bantul.

Balance stocks of relief goods in all regions are then changed. At the end of the first day, Magelang, for instance, suffers from 25 units of medical aid material.

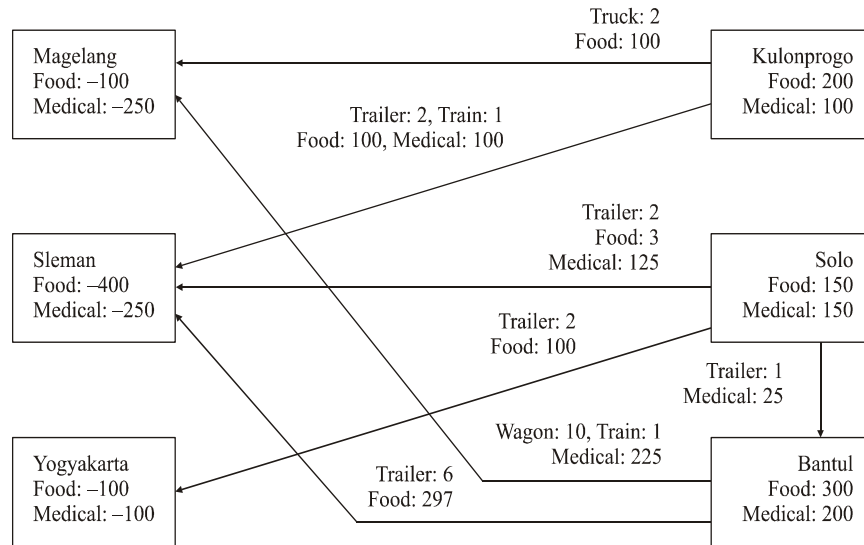


Fig. 2: Relief goods distribution in the first day

This amount is then accumulated with 175 units, the demand for the second day in Table 1. Thus, in the beginning of the second day, total demand for medical aid material for Magelang is 200 units. The overall demand-supply accumulation is described by Table 3. The process is then continued until the last period, where we found that the number of unsatisfied demands becomes zero as indicated by Table 4.

Humanitarian aid worker assignment model: We apply the model to assign volunteers which come from several communities in Yogyakarta. To organize the disaster response process, the local disaster agency, i.e., BPBD Yogyakarta, represents as the coordinator. To illustrate the model we suppose that coordinator sets a 6-day period of emergency response. Each day consists of two time blocks of 7 hours length including rest time, i.e., morning shift (7 AM-2 PM) and afternoon shift (2 PM-21 PM). Thus, during the period we have 12 shifts, denoted by S_1, S_2, \dots, S_{12} .

According to (IDEP, 2011), coordinator identifies 5 tasks, denoted by T_1, T_2, \dots, T_5 , which have to be accomplished as follows:

- T_1 : Search and Rescue (SAR) team, with the task of searching and rescuing survivors and the death
- T_2 : Evacuation team, with the task of preparing evacuation sites and shelters, including securing the evacuation process
- T_3 : Response team, with the task of monitoring the development of disaster, disaster aftershocks and the impact of disasters

- T_4 : Communication team, with the task of maintaining administration issues, emergency and external communication and the needs of volunteers
- T_5 : Welfare team, with the task of delivering first aid, preparing food and estimating basic needs

Since each task requires specific skill, the involvement of community based volunteers are merely in the framework of supporting the responsible bodies, such as Red Cross, Social and Health Services.

Despite there are many community based volunteer groups in Yogyakarta, we here only consider six of them. They are Peraanom Community, Jogja Merapi Electronics (JME), Jalin Merapi, Merapi Lowo Rescue (MLR), Balerante and Turgosari. Peraanom, JME and Jalin Merapi are originally communities of radio fans and now are also supported in disaster communication and rescue. MLR is a volunteer group which focused on the monitoring of natural disaster. All groups are non-formal organization which established by community initiatives. The exact number of members is unknown, varying from time to time ranging from dozens to hundreds. Jalin Merapi is perhaps the most well organized community since they, just to mention a few, facilitate volunteer registration and deployment, relief goods collection and distribution and disaster related information dissemination.

The number of committed volunteers contributed by each group is described in Table 5. In the beginning, i.e., in phase I, there are only 42 committed volunteers. According to workload, coordinator roughly estimates the required number of volunteers in each shift and each task μ_{ki} as given by Table 6, with deviations

$\mu_{kl}^- = 3$ and $\mu_{kl}^+ = 1$. He/she also decides that the ideal number of shifts per volunteer is $w_{ij} = 8$. Based on preference forms submitted by volunteers there are, let say, 31-38 volunteers in each shift and 29-37 volunteers who can handle each task. In fact, this information is just the column-sum of tables α_{ijk} and β_{ijl} , which are not presented in this study. It is also revealed that the ideal number of shifts τ_{ij} varies between 5 and 8, with deviations $\tau_{ij}^- = 1$ and $\tau_{ij}^+ = 2$. It means that the maximum number of shifts allowed by volunteers is 10 and the minimum is 4, thus 6.5 shifts in average. It is indicated that there is a difference on ideal number of shifts between coordinator's expectation and volunteers' preference, pointing out the complexity of assignment problem.

To be more specific, 41% of volunteers can participate in all 12 shifts, 20% in 10 shifts, 29% in 8 shifts and 10% in 6 shifts. Meanwhile, 33% of volunteers have skill to conduct all 5 tasks and respectively 33, 25 and 8% for the rests. At this moment, coordinator doesn't know the adequacy of volunteers to tackle all tasks in each shift and wants to know by executing modified model.

Model in minimizing volunteers scarcity (13) under the new modified constraint (12) provides $s = 111$, suggesting that there is at least 111 volunteers lack which occurs in 15 shift-task pairs, or 7.4 on average, particularly in dealing with task T_1 . As mentioned before, asking extra volunteers is one option which can be taken by the coordinator. He/she may argue that at least it is needed 8 additional volunteers with T_1 skill and available for all shifts. Since the activity is involuntary basis, coordinating favors to invite all groups contributing more volunteers with no specific qualification, as the number of volunteers is now provided by the last column of Table 5. The number of committed volunteers now increases from 42-60 leading to the change in composition of shift-time preferences as described in Table 7.

Number of volunteers in each shift and for each task are then in the range of 44-55 and 41-52, respectively and other parameters are unchanged. Re-execution of the scarcity minimization model provides $s = 0$, showing that the number of volunteers is now adequate. Penalty cost minimization problem with objective function (8) and constraints (9)-(17) is then carried out by setting unit cost $\rho^n = 1$ ($n = 1, 2, \dots, 6$) as shortage and excess from aspiration and ideal levels are equally penalized. The minimum penalty cost and its components are given in Table 8.

Table 6: The ideal level of volunteers number

μ_{kl}	T_1	T_2	T_3	T_4	T_5	Total
S_1	14	14	10	10	8	56
S_2	14	14	10	10	8	56
S_3	14	14	10	10	8	56
S_4	14	14	10	10	8	56
S_5	10	10	8	8	10	46
S_6	10	10	8	8	10	46
S_7	10	10	8	8	10	46
S_8	10	10	8	8	10	46
S_9	8	8	8	8	10	42
S_{10}	8	8	8	8	10	42
S_{11}	8	8	8	10	12	46
S_{12}	8	8	8	10	12	46

Table 7: Volunteers' preferences on shift and task

Shifts	Number of		
	Volunteers	Tasks	Volunteers
12	24 (41%)	5	20 (33%)
10	12 (20%)	4	20 (33%)
8	17 (29%)	3	15 (25%)
6	6 (10%)	2	5 (8%)

Table 8: The minimum penalty cost

Cost	Value	Due to
z_1	127	Volunteer shortages from ideal level
z_2	0	
z_3	2	Shifts shortages from aspiration level
z_4	69	Shifts excess from aspiration level
z_5	23	Shifts shortages from ideal level
z_6	0	
z	221	Total penalty cost

Table 9: Assignment timetable for pareanom community

Group	Volunteer	Shift											
		S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
Pareanom	1		T_5	T_4	T_3	T_5	T_5		T_5		T_4		T_5
	2		T_3	T_2	T_3	T_2	T_3	T_3	T_3		T_3		
	3	T_3	T_5	T_4	T_4	T_4		T_5		T_3	T_4		
	4	T_4	T_4			T_4	T_4			T_2		T_2	T_2
	5	T_5		T_2		T_4		T_5		T_2	T_2	T_5	T_5
	6	T_2	T_4	T_2	T_4	T_4		T_2	T_4	T_3			
	7	T_5	T_5		T_4	T_3		T_5	T_5	T_5			
	8			T_5	T_5		T_4	T_4	T_4	T_5			
	9	T_5	T_5	T_2	T_2	T_5	T_1					T_5	T_3
	10	T_2	T_2	T_2	T_3		T_3	T_3	T_1				T_1

The table tells us that volunteer shortages give the most effect on the penalty cost. When coordinator expects a number of 584 volunteer-shift-tasks (grand total of Table 6), there is only 457 available. It means that, on average, each shift and each task suffer 2 volunteer shortage. However, all volunteers are assigned with average load of 7.6 shifts. A piece of assignment timetable as an extraction of decision variable x_{ijkl} is given in Table 9.

DISCUSSION

In logistics distribution problem discussed in this work, it is assumed that the number of available vehicles is constant in each day. It means that all vehicles should go back to the departure nodes. In fact, this is a simplification of the original model.

In humanitarian workforces assignment problem, an interesting circumstance may arise when there exist volunteer shortages, but at the same time some volunteers are not assigned at all, i.e., $y_{ij} = 0$ for some i and j . In the optimization problem, existence of decision variable y_{ij} suggests that it is not necessary to assign any job at any time block for every volunteer whenever an optimal solution is achieved. Nevertheless, the situation is obviously contradictory with the characteristic of volunteer assignment in avoiding the non utilization of volunteer labor. The Coordinator should work out this by relaxing constraints, changing parameters, or even experimenting another objective function such as maximization of $\sum_{i,j} y_{ij}$. From the side of volunteer, he/she may reconsider his/her preferences on shift and task.

CONCLUSION

In this study we have utilized OR/MS approaches in dealing with disaster management. In particular, we have implemented logistics distribution model and humanitarian aid workforces assignment model in Mt. Merapi disaster operation. The former is formulated in a mixed integer linear programming aiming to minimize the amount of unsatisfied demand. The latter is expressed in a goal programming setting aiming to minimize the penalty cost caused by deviation from ideal and aspiration levels. We expect from this work to provide a basis for an effective and optimal emergency response operation through OR/MS. For wider application, the scale of the problem can be easily adjusted, for instance, by considering a distribution model among lower level of regions or by incorporating operational cost minimization. The humanitarian worker assignment model can also be straightforwardly adapted to cases with a large number of community groups.

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