Multi-objective Location-Transportation Problem for Relief Distribution

A Case Study of Mount Bromo Eruption

Joniarto Parung, Amelia Santoso(✉), Dina Natalia Prayogo, Felita Griselda, and Adi Tedjakusuma

University of Surabaya, Surabaya, Indonesia
Amelia@staff.ubaya.ac.id

Abstract. The problem that is often encountered in every natural disaster is material damage and even loss of life; thus, systematic steps to reduce or prevent the impact of disasters are needed. A quick response is the main thing to carry out disaster management when a disaster occurs. The steps taken are mobilizing and deploying emergency services to protect people and reduce material damage within the affected areas. The primary response to minimize the impact is to distribute humanitarian aid. The distribution of aid includes 2 aspects: the speed of delivery of aid and the fulfillment of all the needs of disaster victims. This aspect is related to predicting the amount and time of distribution of necessities to be adequately distributed. Prediction of demand and distribution is influenced by many factors, including distance, availability of vehicles, number of affected people, operational time of aid providers, local conditions such as roads, needs of population groups, etc. This study aims to modify the existing mathematical model for the Multi-Objective Location-Transportation Problem. This modification was carried out to determine the number and time of effective delivery of essential goods based on heterogeneous vehicle capacities. This model was then applied to a case study for the distribution of goods during a volcanic eruption using data from Mount Bromo, East Java, Indonesia. The model development and application results in the case study show information on the number and timing of effective delivery of essential humanitarian aid items based on the available vehicle capacity at the location according to the conditions of the disaster location.

Keywords: natural disaster · eruption · multi-objective problem · humanitarian aids

1 Introduction

Natural disasters are damage events caused by an event or a series of events caused by nature that are difficult to avoid. Several natural disasters often encountered include earthquakes, volcanic eruptions, tsunamis, floods, hurricanes, and landslides. Natural disasters will generally be followed by material damage and even loss of life. According to Kaviyani et al. [1], there has been significant growth in fatalities and financial losses caused by natural disasters in recent years. This has encouraged researchers and practitioners in various fields to make intensive efforts to deal with natural disasters through

W. R. Murhadi et al. (Eds.): INSYMA 2022, AEBMR 223, pp. 1193–1201, 2023.
https://doi.org/10.2991/978-94-6463-008-4_147

disaster management. Disaster management is generally divided into four stages: mitigation, preparedness, response, and recovery [2]. The mitigation and preparedness phase occurs before the disaster, aiming to determine the necessary steps to reduce or prevent the impact of a disaster and develop an action plan to be implemented in the event of a disaster. When a disaster occurs, response and recovery phases take place. The response, or intervention phase, is the mobilization and deployment of emergency services to protect people and reduce material damage within the affected area. The recovery phase sets out the steps towards a return to normal, i.e., the standard of living of the same quality as before the disaster occurred.

This paper focuses on the response phase for distributing aid in a natural disaster. The distribution of aid includes 2 aspects: the speed of delivery of aid and the fulfilment of all the needs of disaster victims. According to Gossler [3], the budget of aid organizations is generally limited, so costs for providing transportation services need to be saved, which often causes aid distribution decisions to be impacted. In this regard, it is essential to understand the relationship between transportation and the distribution of humanitarian aid to disaster areas. Several studies have linked the scheduling of humanitarian aid deliveries to the availability of transportation facilities and meeting the needs of disaster victims at the right location.

One of the studies that relates the aspects of transportation and affected locations in a mathematical approach is [4]. The mathematical model was developed with multi objectives. The model developed by Abounacer et al. [4] revealed 3 objectives: (1) to minimize the total transportation time to area i, (2). to minimize the distribution centers, and (3) to minimize the total unfulfilled demand. In this mathematical model, two important variables to consider are the affected location and transportation to reach the affected location. To design a humanitarian aid distribution network, the affected location variables need to be known. By knowing the affected location, the number of affected people can be identified so that the amount of humanitarian aid such as water, food, medical goods, and other equipment and the best location for the distribution center of humanitarian aid can be determined. Transportation variables are needed to distribute humanitarian aid to affected locations at the right time and the right amount. These two variables are the core of the objectives that will be resolved simultaneously in the case of humanitarian assistance when a natural disaster occurs at the responsive stage. The model developed by Abounacer [4] was tested in natural disaster cases in Indonesia, through modifications according to the conditions at the disaster site. The problem discussed is how this form of change is carried out to be applicable to local conditions in Indonesia.

According to Berkoune et al. [5], a disaster is a complex situation in which the flow of various relief goods must be transported to the affected population using available vehicles. The relief items needed are generally sent from one distribution center to a delivery point representing the location where disaster victims will get aid. As transportation needs are many and varied, disaster managers often request almost any vehicle available, even if some of them are not very efficient for delivering certain types of goods. This condition often causes the relief goods not to be delivered as needed at the wrong location.

One of the main concerns about disaster transportation is the lack of certainty, which leads to the failure to distribute humanitarian aid logistics increasing fatalities effectively. To minimize or eliminate this problem, several researchers have developed powerful optimizations. Gossler et al. [3] developed a game theory model to investigate the effect of transportation costs on distribution decisions in long-term relief operations and evaluate measures to improve the fulfilment of beneficiary needs. Singhtaun [6] proposed a mathematical model and survey performance of the algorithm to solve the transportation-location problem of humanitarian aid and solved it with the help of a branch-limit algorithm. Vitoriano [7] proposed several steps to solve the distribution problem. Vitoriano [7] also developed a multi-variable optimization model based on the considered aspects. The proposed model is the core of a decision-making backup system to assist humanitarian aid. Huang et al. [8] developed the principles of humanitarian distribution with three objectives, including saving tools, delay costs, and fairness. Wang et al. [9] focused on the post-earthquake phase and proposed a non-linear integer model for the problem of position distribution and aid routing problems considering travel time, total cost, and reliability of dispatch missions and genetic algorithms. [10] studied and described a real-world Multi-Constraints Emergency Transportation Problem in disaster response under travel time uncertainty whose purpose is to determine a series of flights and routes and the assignment of aircraft and other vehicles to deliver the necessary humanitarian assistance to the disaster area as soon as possible. This model is a variant of the Vehicle Routing Problem (VRP), which considers heterogeneous fleets with multi-depots delivering supplies to customers to minimize the maximum travel time of all routes where experts predict vehicle travel times due to damaged ground transportation networks and impact levels are not known.

All the models and approaches described above have advantages and disadvantages, so they cannot be used in all situations. In this paper, the model by Abounacer et al. [4] uses a homogeneous means of transportation, and the affected locations are categorized based on data. This ideal condition does not always occur in disaster areas like in Indonesia, where vehicles are not always homogeneous in capacity, volume, and speed, so the model Abounacer et al. [4] was modified according to field conditions. The field condition used as a case study is the condition at Mount Bromo, East Java, Indonesia.

2 Research Method

In terms of paradigm, this research can be grouped into positivist research, in which the ontology sees reality objectively. The research strategy is included in the analytical category. In this study, the initial model of Abounacer et al. [4] is implemented as is with actual data and then analyzed. After finding the need for modification, the initial model was developed based on logic according to the modified findings from the real situation in the field. In this paper, only 2 objective functions were shown, different from the initial model with 3 objective functions, because the location for collecting aid for disaster victims is only 1 Regional Income Management Agency (BPPD), so the number of agents (first-aiders) needed to open and operate the selected distribution centers will always be a minimum. The second objective function of the initial model is no longer relevant.

Primary data collection was done through direct observation, field visits, and interviews to verify data, including discussions with National and Political Unity Agency (Bakesbangpol) East Java Province, Regional Disaster Management Agency (BPBD) Probolinggo Regency, and Sumber Asih and Sukapura, Probolinggo Sub-district heads. Primary data includes actual data regarding the logistics needs of the community when an eruption occurs. Primary data is also in the form of the most affected locations, the psychological and economic impact of the eruption on the environment, the type of eruption, the flow of the eruption, the type of mountain, community activities, data on vehicles used for shipping, and the number of workers. Secondary data are data obtained from the historical history of Mount Bromo. The data were obtained through the internet and related official websites, such as data on the distance of goods delivery from the sub-district to the village, data on the size and dimensions of vehicles, volume data, and the weight of materials for logistics needs.

3 Results and Discussions

One example of a natural disaster that has occurred and has the potential to happen again on Java Island is the eruption of Mount Bromo, East Java, Indonesia. Mount Bromo is located in four regencies: Probolinggo, Pasuruan, Lumajang, and Malang. Mount Bromo has erupted more than 60 times since 1767. The eruption interval of Mount Bromo occurs every 5 years and increases every 30 years. The most significant Bromo eruption in the 21st century occurred in 2004. In 2004, the Bromo eruption killed 2 tourists under the sand, and 5 others suffered minor injuries (IRBI BNPB, 2013).

The eruption of Mount Bromo produced a thick cloud of dust that hampered the community's daily activities, thus having an impact on meeting the needs, activities, and social losses of the community. The conditions of people's lives that must be met rice, sardines, masks, instant noodles, drinking water, etc., become difficult to fulfil because satisfying their needs is hampered by the activity of Mount Agung. Volcanic eruptions impact distribution failures, including shortage of raw materials, too long delivery times, etc. The failure of distribution has an impact on social losses for the community in the form of loss of life, non-fulfilment of the necessities of life, hunger, disease, etc.; thereby, it is necessary to ensure the time and quantity of goods for logistics needs that can meet the needs of the community properly.

The Regional Disaster Management Agency (BPBD), as the government agency that regulates the distribution of the necessities of life for the community, plays an important in dealing with the impact of natural disasters. BPBDs are divided into 2 types based on their coverage area, namely Regency and Provincial-level BPBDs. At the time of the Mount Bromo eruption, the closest BPBD of Probolinggo Regency was responsible for sending goods to the affected villages. BPBD sends goods to the village head and then distributes them to the community. Several villages are grouped into several areas so that the capacity of vehicles with goods distributed is maximized. BPBD encountered several problems that arose: the lack of the number of daily necessities that were distributed and the timing of the delivery of goods to the village ahead was uncertain.

Based on the problems that arise in BPBD, literature studies and data processing are carried out to help find appropriate solutions. The researchers conducted a literature study based on the mathematical model developed by Abounacer et al. [4] because it is suitable for solving this problem, namely the multi-objective location-transportation problem, which aims to minimize delivery times and the number of unmet community needs. The mathematical model developed by Abounacer et al. [4] discussed that the capacity of the goods sent should be adjusted to the number of community needs, the type of vehicle transporting goods, and the maximum capacity of the vehicle that transports aid goods allocated to the village. Vehicles have a maximum operating time of 24 h; if the vehicle fails to make deliveries within the available time, it is necessary to increase the number of vehicles and not the capacity. The number of vehicles needs to be added and not the capacity because this can increase the vehicle's operating time, which can exceed the maximum limit of vehicle operation. Data processing for mathematical models was carried out by inputting the LINGO11 program language with adjustments, then assisted by Microsoft Excel 2010, and entering the data needed for later analysis regarding the solution to achieve the desired goal. Sensitivity analysis was carried out to determine the effect of changes in one parameter, namely demand, to anticipate the time.

The development model to be applied to the volcanic eruption at Mount Bromo is described below. Table 1 exhibits the modifications of the original model.

Table 1. Comparison of the Abounacer et al. [4] model and the proposed model

Category	Abounacer et al. model	The proposed model
Method	Multi objective location transportation problem	Multi objective location-transportation problem
Objective	To determine the distribution time To determine the number of demand points and a minimal number of workers To know the number of unfulfilled demands	To determine the distribution time To know the number of unfulfilled demands
Demand	Obtained through disaster related data	Adapted to the population and the number of needs per person
Affected location	Categorized based on data	Manually categorized based on vehicle loading capacity and population demand. The village location is categorized into several areas
Cost	Not considered	Not considered
Type of Vehicles	homogeneous vehicles that are used to load all requirement	Heterogeneous vehicles that are used to load product and another vehicle to load water
Time window	Not considered, as minimum as possible	Not considered, as minimum as possible

The modified mathematical model developed from [4] is shown below. The multi-objective location-transportation model aims to determine the minimum duration, number of workers and the delivered product.

Index:

i = area; $i = \{1, \ldots, n\}$ j = product; $j = \{1, \ldots, p\}$
l = BPBD; $l = \{1, \ldots, u\}$ h = vehicle type; $h = \{1, \ldots, m_l\}$
k = vehicle; $k = \{1, \ldots, u_{hl}\}$ v = *trip*; $v = \{1, \ldots, r\}$

Parameter:

d_{ij} = demand of product j in area i
S_l = BPBD capacity of product
s_{lj} = BPBD capacity of product j
N_l = number of workers in BPBD
t_{il} = traveling time from BPBD *to* area i
m_l = number of available vehicles in BPBD
u_{hl} = number of vehicle type h in BPBD
τ_{lh} = docking time of vehicle type h in BPBD
Q_h = loading weight capacity of vehicle type h
V_h = volume capacity of vehicle type h
α_{jh} = loading and unloading time of product j *at vehicle type h*
D_h = the maximum working time of vehicle type h
w_j = the weight of each unit of product j
v_j = the *volume* of each unit of product j
r = the maximum number of trips that are needed by vehicle

Decision Variables:

y_i = 1 if there are shelter in BPBD, 0 otherwise
x_{ilhkv} = 1 if there are visiting to area i in BPBD with vehicle k, *vehicle type h* on trip v
Q_{ijlhkv} = the product j quantity that delivered to area i of BPBD using the vehicle k type-h on delivery *trip* v
P_{jl} = *the* available product j quantity in BPBD.

The mathematical model.

The first objective function is to minimize the total transportation time to area i.

$$\text{Min } f_1 = \sum_{i=1}^{n} \sum_{l=1}^{u} \sum_{h=1}^{m_l} \sum_{k=1}^{u_{hl}} \sum_{v=1}^{r} \left((2t_{il} + \tau_{lh} x_{ilhkv}) + \sum_{j=1}^{p} \alpha_{jh} Q_{ijlhkv} \right) \tag{1}$$

The second objective function is to minimize the total unfulfilled demand

$$\text{Min } f_3 = \sum_{i=1}^{n} \sum_{j=1}^{p} \left(d_{ij} - \sum_{l=1}^{u} \sum_{h=1}^{m_l} \sum_{k=1}^{u_{hl}} \sum_{v=1}^{r} Q_{ijlhkv} \right) \tag{2}$$

Subject to:

The product quantity that delivers to each area has to be less than demand in the area

$$j \ \sum_{l=1}^{u} \sum_{h=1}^{m_l} \sum_{k=1}^{u_{hl}} \sum_{v=1}^{r} Q_{ijlhkv} \leq d_{ij}; \qquad i = 1, \ldots, n; \ j = 1, \ldots, p \qquad (3)$$

The quantity product that delivers by vehicle has to be less than available products in BPBD.

$$\sum_{l=1}^{n} \sum_{h=1}^{m_l} \sum_{k=1}^{u_{hl}} \sum_{v=1}^{r} Q_{ijlhkv} - p_{jl}, \leq 0; \qquad j = 1, \ldots, p; \ l = 1, \ldots, u \qquad (4)$$

The operation time of vehicle k type h that are in BPBD has to be less or equal to the maximum vehicle operation time

$$\sum_{i=1}^{n} \sum_{v=1}^{r} ((2t_{il} + \tau_{lh})x_{ilhkv} + \sum_{j=1}^{p} \alpha_{jh} Q_{ijlhkv}) \leq D_h y_l; \qquad l = 1, \ldots, u;$$
$$h = 1, \ldots, m_l; \ k = 1, \ldots, u_{hl} \qquad (5)$$

The total loading of delivered product $\left(w_j Q_{ijlhkv}\right)$ is equal and less than vehicle capacity $(Q_h x_{ilhkv})$. It assumes deliver the similar product

$$\sum_{j=1}^{p} W_j Q_{ijlhkv} \leq Q_h x_{ilhkv}; \qquad i = 1, \ \ldots, \ \text{n}; \ j = 1 \ldots, p-1; \ l \epsilon L_i; \ h = 1;$$
$$h = 1; \ k = 1, \ldots, u_{hl}; \ v = 1, \ldots, r \qquad (6)$$

The product volume that delivers by each vehicle has to be less than or equal to maximum capacity of vehicle loading. There is no difference among product that is loaded.

$$\sum_{j=1}^{p} v_j Q_{ijlhkv} \leq V_h x_{ilhkv}; \qquad i = 1, \ldots, n; j = 1, \ldots, p-1; l \epsilon L_i; \qquad (7)$$

Vehicle that delivers product except water ($j = 1, \ldots, p-1$), using the first vehicle type.

First vehicle ($k = 1, \ldots, u_{hl}$), in all of delivery trip ($v = 1, \ldots, r$).

$$V_j Q_{ilhkv} \leq V_h x_{ilhkv}; \qquad i = 1, \ldots, n; j = 7; l \epsilon L_i; h = 2;$$
$$k = 1, \ldots, u_{hl}; \ v = 1, \ldots, r \qquad (8)$$

The product in BPBD has to be fulfilled before delivery to area i

$$\sum_{j=1}^{p} p_{jl} \leq S_l y_l; \qquad l = 1, \ldots, u \qquad (9)$$

The capacity of each product j in BPBD has to be fulfilled before delivers to area i

$$p_{jl} \leq S_{lj}; \qquad j = 1, \ldots, p; l = 1, \ldots, u \qquad (10)$$

$$y_l \epsilon \{0, 1\}; \qquad l = 1, \ldots, u \qquad (11)$$

$$x_{ilhkv} \epsilon \{0, 1\}; \quad i = 1, \ldots, n; l \epsilon L_i; h = 1, \ldots, m_l;$$

$$k = 1, \ldots, u_{hl}; v = 1, \ldots, r \quad (12)$$

$$Q_{ijlhkv} \geq 0; \quad i = 1, \ldots, n; l \in L_i; h = 1, \ldots, m_l;$$

$$k = 1, \ldots, u_{hl}; v = 1, \ldots, r \quad (13)$$

$$p_{jl} \geq 0; \quad j = 1, \ldots, p; l = 1, \ldots, u \quad (14)$$

4 Conclusion

Through the research conducted, it can be concluded that:

The mathematical model developed by Abounacer et al. [4] can be used to determine the minimum time of distribution of daily necessities products found on Mount Bromo. The model can be used, but some formulas and objective functions need to be adjusted so that they can match the actual conditions in the form of non-homogenous vehicles.

The mathematical model developed by Abounacer et al. [4] can be applied to determine the minimum quantity of unmet demand from the distribution of daily necessities found on Mount Bromo. Models can be applied with formula adjustments.

Sensitivity analysis can be applied by changing the demand parameter to objective function 1, which is to know the distribution time, and objective function 2, which is to know the number of shipments that are not delivered.

Acknowledgments. The authors gratefully thank and acknowledge that the Ubaya Center of Disaster Management supported this study, which was initially co-funded by Erasmus + Programme by the European Union. This center aims to maximize the impact and expose the disaster management system that will be developed for Indonesia and its community.

References

1. Kaviyani-Charati, M., Heidarzadeh Souraki, F., & Hajiaghaei-Keshteli, M. (2018). A robust optimization methodology for multi-objective location-transportation problem in disaster response phase under uncertainty. *International Journal of Engineering, 31*(11), 1953–1961.
2. Altay, N., & Green III, W. G. (2006). OR/MS research in disaster operations management. *European Journal of Operational Research, 175*(1), 475–493.
3. Gossler, T., Wakolbinger, T., Nagurney, A., & Daniele, P. (2019). How to increase the impact of disaster relief: A study of transportation rates, framework agreements and product distribution. *European Journal of Operational Research, 274*(1), 126–141.
4. Abounacer, R., Rekik, M., & Renaud, J. (2014). An exact solution approach for multi-objective location–transportation problem for disaster response. *Computers & Operations Research, 41*, 83–93.
5. Berkoune, D., Renaud, J., Rekik, M., & Ruiz, A. (2012). Transportation in disaster response operations. *Socio-Economic Planning Sciences, 46*(1), 23–32.

6. Singhtaun, C. (2015). An exact algorithm for location–transportation problems in humanitarian relief. *International Journal of Industrial and Manufacturing Engineering, 9*(3), 815–819.
7. Vitoriano, B., Ortuño, M. T., Tirado, G., & Montero, J. (2011). A multi-criteria optimization model for humanitarian aid distribution. *Journal of Global Optimization, 51*(2), 189–208.
8. Huang, K., Jiang, Y., Yuan, Y., & Zhao, L. (2015). Modeling multiple humanitarian objectives in emergency response to large-scale disasters. *Transportation Research Part E: Logistics and Transportation Review, 75*, 1–17.
9. Wang, H., Du, L., & Ma, S. (2014). Multi-objective open location-routing model with split delivery for optimized relief distribution in post-earthquake. *Transportation Research Part E: Logistics and Transportation Review, 69*, 160–179.
10. Shao, W., Liu, X., Chen, J., & Lu, Z. (2021). A study of multi-constraints emergency transportation problem in disaster response. *Asia-Pacific Journal of Operational Research, 38*(02), 2050050.