Optimization of Medical Relief Shelter Location in Disaster Condition: A Case Study in Jakarta, Indonesia

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Abstract: Indonesia, like many other countries, frequently faces natural disasters, and its capital, Jakarta, does not stray from this trend. Despite this, Jakarta's budgetary priorities often prioritize other areas over disaster relief. Consequently, one significant impact of natural disasters is the emergence of victims requiring accessible health services. which are often insufficient. This combination of budget constraints and healthcare service inadequacies intensifies the demand for accessible medical relief shelters that can be deployed within a certain budget. Integer programming is used to model a Facility Location Problem that meets these criteria. An optimal solution is found using this model. However, there are some shortcomings of the current model that can be improved in future research.

Keywords: facility location problem; limited budget; medical relief shelter; optimization

1. Introduction

Natural disasters happen in every part of the world that cause damage, disruptions, destruction, loss of human life, and human suffering[1]. The number and magnitude of disasters have been exponentially increasing since 1950s[1]. In 2022, there were 387 natural disasters recorded that affected 185 million people and about 30.7 thousand people died, and economic damage was estimated around 223.8 billion USD[2]. According to the International Disaster Database, Asia is the most affected continent by disaster, such as floods, earthquakes, and storms[3]. Jakarta, Indonesia's capital and economic center, which is in Asia region, does not stray far from this fact.

In Jakarta, floods are the most common natural disasters. During the last five years, the flood that occurred at the beginning of 2020 was the worst in Jakarta. More than 31 thousand people were impacted by this event and had to be evacuated to 269 locations[4]. Out of all these evacuees, there were about 5,000 people that needed and had gotten healthcare during the first three days of the floods[4]. This indicates that healthcare is essential in facing natural disasters.

During disasters, healthcare can be divided into two types: healthcare in hospitals and healthcare that are given in the field[5]. The latter is used whenever patients are unable to access hospitals, and these types of healthcare are usually in the form of medical relief shelters. This inability to access these healthcare facilities often happens in Jakarta, especially during floods situation[6]. For instance, the floods damaged the road infrastructure, which could restrict accessibility to healthcare facilities for the victims[7]. Moreover, the lack of medical equipment and material, such as medicines, beds, and other equipment, as well as the lack of medical personnel might worsen the situation[8].

Healthcare during disasters in Indonesia are often inadequate. This can happen because of several things, including damaged healthcare facilities, inadequate medical supplies, lack of healthcare personnel, and insufficient operational budget[8]. Based on this information, healthcare in the form of medical relief shelters need to be placed in accessible locations and they need to be adequate.

Placing down medical relief shelters is an important task in disaster relief. However, in terms of budgeting, Jakarta still has other priorities outside of disaster relief. From 2018 to 2020, the budget for the handling of floods had been decreased by a total of 26%[9,10]. Besides, the Regional Agency for Disaster Countermeasure (Badan Penanggulangan Bencana Daerah or BPBD), which is an organization that deals with disaster management in Jakarta, only got 0.02% of Jakarta's total budget[9].

From this, there are three main points. The first point is that natural disasters in Jakarta create the need for healthcare facilities such as medical relief shelters. The second point is that healthcare in emergency situations must be adequate, which can be accomplished by fulfilling the needs of patients and by making these facilities accessible. Accessibility can be done by placing medical relief shelters near the location of patients. The third point highlights the importance of budgeting in disaster relief efforts. Therefore, it is crucial to identify the most suitable sites for medical relief shelters during emergencies such as disasters considering the limited budget availability.

This research aims to model how to choose the medical relief shelter locations from several candidate locations in order to maximize the reachability to potential patients or victims when a disaster occurs by considering the budget availability. This research used the case of Jakarta, Indonesia as a case example under three budget conditions, which are normal (100% of the total budget), pessimistic (50% of the total budget), and optimistic (150% of the total budget).

This study employs an exact approach, specifically the integer programming method, to ensure the optimal solutions are obtained. However, using the exact method has a limitation as it requires relatively long computational time to arrive at a solution.

The rest of this paper is structured as follows: Section 2 provides the literature study that is relevant to this research. Section 3 outlines the methodology employed in this research. The findings of this study and the analysis are provided in Section 4. Finally, the conclusion and suggestion are presented in Section 5.

2. Literature Review

This section will briefly explain the concepts related to this research topic, including humanitarian logistics and facility location problem, especially in humanitarian logistics.

2.1 Humanitarian Logistics

Because of the increase in frequencies and impacts of disasters, research focuses on humanitarian logistics and supply chain operations has been recently increasing. Humanitarian logistics is defined as a process of planning, implementing, and controlling the flow and storage of goods, materials, and information, from the point of source to the point of consumption aiming to alleviate the suffering of susceptible people in a cost-effective and efficient manner[11)]. Thus, humanitarian logistics can be stated as all types of logistical activities to help suffering people.

There are three main phases in humanitarian logistics operation: mitigation and preparation, response, and reconstruction[1,12)]. The mitigation and preparation phase focuses on reducing the disaster occurrence probability and decreasing the severity of the impacts, preparing and planning the activities that need to be performed following the disaster occurrence. For instance, the study of Berawi et al.[13)] has given the method to determine and to prioritize the victims to be rescued during emergencies. This method was prepared to be used in the occurrence of natural disaster, so the response time can be quicker, increase the victims' survival rate, and reduce the victims' severity. Another study predicts the potential areas where disaster might occur, so mitigation actions can be prepared prior to the occurrence of the disaster and the risks, damage, and losses might be reduced[14)]. The response phase focuses on reducing the impacts of disaster after its occurrence by conducting immediate response to help the victims in order to prevent additional losses and suffering. While the reconstruction phase focuses on post-disaster activities to recover and restore the affected area to be back to normal condition. Residential relocation[15)] is an activity in reconstruction phase.

In humanitarian logistics, there are supply chains that send supplies to specific people at specific locations during specific times with specific quantities. These supply chains have three main lines, flow of material, flow of information, and flow of money[16)]. The flow of materials includes supplies that are sent from donors to receivers. The flow of information includes demand forecasts and status reports that ensure proper communication. The flow of money includes money and payments.

2.2 Facility Location Problem in Humanitarian Logistics

In humanitarian relief operations, one of the most critical decisions is related to facility location[17)], including the location of medical supplies, distribution center, warehouse, evacuation area, healthcare facilities, etc. Some previous research (Dekle et al.[18)], Hale and Moberg[19)], Kongsomsaksakul et al.[20)], Balcik and Beamon[21)], Paul and Batta[22)], Ablanedo-Rosas et al.[23)], Horner and Downs[24)], Mete and Zabinsky[25)], Zhu et al.[26)], Jabbarzadeh et al.[27)], Bayram et al.[28)], Kilci et al.[29)], Salman and Yücel[30)], Marcelin et al.[31)], Stienen et al.[32)], and Yassin et al.[33)]) have discussed the facility location problems in humanitarian logistics operations during emergency situation.

In the Facility Location Problem (FLP), a set of facilities is chosen to maximize certain requests (given by customers) and meet certain restrictions[34)]. There are four components in the FLP, namely customers who are at a particular point or route, the facility to be chosen for its location, the place where customers and facilities are located, and measurement standards to indicate the distance or time between the customer and facility[34)].

Boonmee et al.[1)] show that the facility location problem is an approach often used to deal with humanitarian logistical problems in a disaster. There are five types of FLPs that are usually used for humanitarian logistical problems, namely minisum, set covering, maximal covering, minimax, and obnoxious[1)]. In the minisum FLP type, the purpose of the problem is to select the locations of the facility and minimize the total distance between facility points and demand points. In the set covering FLP, the objective is to minimize the cost of all open facilities with the condition that all points of demand can be covered. The problem of maximal covering maximizes the demand point coverage by all facilities. Minimax problems minimize the maximum distance from the demand point to the facility point. Unlike the other problems, the obnoxious FLP problem aims to maximize the distance of demand to the point of facility. This problem can be used to select locations far from factories, nuclear power plants, and others.

Many researchers used the minisum FLP models to determine the optimal facility location to support humanitarian operations, which medical relief shelter is one of the critical facilities to be determined since it directly connects to the disaster victims[35]. Gu et al.[5] proposed a humanitarian minisum FLP model to decide the best facility locations for medical relief shelters that consider the amount of the budget in one of its constraints. Figure 1 shows the illustration of the model proposed by Gu et al.[5], where there are three locations: Patients, Medical Relief Shelters, and Medical Deployment Centers. The points of Medical Relief Shelters serve as potential options for selecting the locations of relief shelters in FLP issues. The selection of points from the candidate location is based on the location of the patient, so the total cost is less than the total budget.

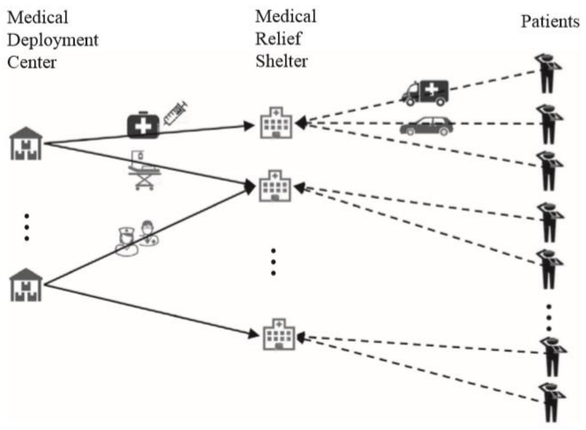

Fig. 1: FLP Model Illustration

3. Methodology

This study uses an integer programming method as an exact method of optimization, so the solution obtained is an optimal solution[36,37]. Gurobi Optimizer is used because of its relatively fast solving time and its ease of access and use. The optimization results are analyzed based on three budget scenarios, namely 100% of the total budget, 50% of the total budget, and 150% of the total budget.

3.1 Data Collection

The data collected and used in this study are data on medical supply centers, relief shelters, patients, relief shelter needs, transportation, and costs. All this data is obtained based on the floods that occurred in Jakarta at the beginning of 2020.

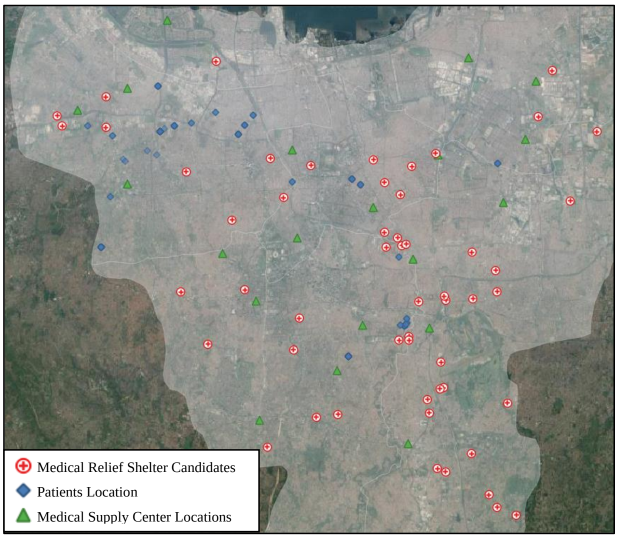

Fig. 2: Visualization of Medical Supply Centers, Medical Relief Shelters, and Patients' Locations.

The medical supply center is the location where medical supplies are stored, which are the hospitals that partner with Jakarta government. The intended medical supplies are medicines and medical equipment needed by patients at the relief shelter.

Relief shelter data is data of candidate location points for the facility location problem optimization process. These locations were acquired from sites previously designated as health posts during the Jakarta flood in early 2020. This data includes the coordinates of each candidate location, as well as fixed and variable costs if the location is chosen.

Patients are data about people who need health services at the relief shelter. Patient data include patient location and patient severity values. Severity value is an assessment of how severe the patient's condition is. If the severity value in a patient exceeds a certain threshold, then that patient is categorized as an emergency patient. Data regarding the number and location of patients were obtained from the proportion of disaster victims at 28 evacuation sites, while the severity values were randomly assigned.

Medical supplies contain data on the amount, type, volume, and price of medicines and medical equipment needed by patients. This data was obtained from the Jakarta Flood Disaster Contingency Plan.

Transportation data includes the type of transportation, vehicle capacity, fixed costs, and variable costs related to the transportation of medical supplies from the medical supply center to the relief shelter. The type of vehicle used is truck, as it is the type of transportation used by Jakarta government in disaster management activities.

Cost data is other cost data that is not related to transportation, as well as maximum budget limits that can be used. These data were obtained from the Jakarta Flood Disaster Contingency Plan and Jakarta's Government Budget Plan.

The detailed facility locations, including medical supply centers, medical relief shelter candidates, and patients' locations are presented in Fig. 2.

3.2 Facility Location Problem Optimization Model Development

The optimization model was modeled in Python programming language. The mathematical model of the Facility Location Problem adopted from the study of Gu et al.[5] is as follows:

Parameters

Location

I	=	Set of individual patients, $i \in I$
L_R	=	Set of candidate locations for medical relief shelter, $j \in L_R$
L_S	=	Set of Medical Supply Center Locations, $l \in L_S$
D_{ij}	=	Distance from patient i location to medical relief shelter j
D_{lj}	=	Distance between Medical Supply Center Locations l and medical relief shelter j

Patient Condition

S_i	=	Severity of patients i
T	=	Severity threshold for emergency patients
E_i	=	1 if patient i is in case of emergency, 0 otherwise

Medical Supplies

K	=	Set of different types of medical supplies, $k \in K$
A_k^e	=	Quantity of medical supply k needed for emergency patients
A_k^n	=	Quantity of medical supply k needed for non-emergency patients
MK_{lk}	=	Maximum quantity of medical supply k at medical supply center l
V_k	=	Volume of medical supply k

Costs

CV	=	Vehicle cost per vehicle
CT	=	Transportation cost per vehicle per unit distance
CCF_j	=	Fixed construction cost of medical relief shelter j
CCV_j	=	Variable construction cost per capacity of medical relief shelter j
CO_j	=	Operating cost of medical relief shelter j
CP_k	=	Procurement cost of medical supply k

Others

MV	Maximum capacity of a vehicle in volume
B	Total relief budget
M	A large number

Decision Variables

y_j	1 if a medical relief shelter j is constructed, 0 otherwise, where $j \in L_R$
cy_j	Capacity of medical relief shelter j
z_{ljk}	Quantity of medical supply k transported from medical supply l to medical relief shelter j, where $l \in L_S$
x_{ij}	1 if patient i is assigned to medical relief shelter j, 0 otherwise

Objective Function

$$Max \sum_i \sum_j \frac{S_i}{D_{ij}} x_{ij} \tag{1}$$

Constraints

$$\sum_i x_{ij} \leq cy_j, \forall_j \in L_R \tag{2}$$

$$A_k^e \sum_i x_{ij} E_i + A_k^n \sum_i x_{ij}(1 - E_i) \leq \sum_l z_{ljk}, \forall k \in K, \forall_j \in L_R \tag{3}$$

$$\sum_j z_{ljk} \leq MK_{lk}, \forall k \in K, \forall l \in L_s \tag{4}$$

$$\sum_j CCV_j cy_j + \sum_j CCF_j y_j + \sum_j CO_j cy_j + \sum_l \sum_j \sum_k CP_k z_{ljk} + \frac{1}{MV} \sum_l \sum_j \sum_k z_{ljk} V_k (CV + CT \times D_{ij}) \leq B \tag{5}$$

$$cy_j \leq My_j, \forall j \in L_R \tag{6}$$

$$x_{ij} \leq y_j, \forall j \in L_R, \forall i \in I \tag{7}$$

$$\sum_j x_{ij} \leq 1, \forall i \in I \tag{8}$$

$$y_j \in \{0,1\}, \forall j \in L_R \tag{9}$$

$$x_{ij} \in \{0,1\}, \forall i \in I, \forall j \in L_R \tag{10}$$

$$cy_j \geq 0, \forall j \in L_R \quad (11)$$

$$z_{ljk} \geq 0, \forall l \in L_s, \forall j \in L_R, \forall k \in K \quad (12)$$

The model has two main objectives, to prioritize patients with high severity and facilitate patient access to relief shelters. Therefore, the objective function in Eq. (1) aims to maximize the patient's severity while minimizing their distance to relief shelters. The constraint function in Eq. (2) aims to guarantee that the number of patients at a medical relief shelter remains within its capacity. Constraint function in Eq. (3) ensures that the number of medical supplies sent to a medical relief shelter is as needed. Constraint function in Eq. (4) ensures that the number of medical supplies sent from a medical supply center does not exceed the stock at that location. The constraint function in Eq. (5) is a cost constraint function, where the total of all costs is ensured to be less than the total budget. Constraint function in Eq. (6) ensures that medical relief shelter candidates that are not selected will have a capacity of zero. The constraint function in Eq. (7) is a function that regulates that patients cannot be placed in medical relief shelters which were not chosen. constraint function in Eq. (8) guarantees that each patient is allocated to only one medical relief shelter. The natures of decision variables are defined in the constraint functions in Eq. (9), Eq. (10), Eq. (11), and Eq. (12), where medical relief construction (y_j) and patient allocation (x_{ij}) decisions are binary, and capacity of medical relief shelter (cy_j) and quantity of medical supply transported (z_{ljk}) have to be non-negative.

4. Result and Discussion

There are three budget scenarios that are included in the model: normal condition, pessimistic condition, and optimistic condition. All three scenarios relate to the amount of the budget. The normal scenario uses the assumption that the amount of the budget is the same as the initial budget. The optimistic scenario was obtained when there is an additional external budget outside the initial budget, while the pessimistic condition was obtained with the assumption that the budget could be reduced if it had been used at the beginning of the year.

The data used to obtain the optimization solution in normal condition are in the form of 54 points of relief shelters, 651 patients spread over 28 points of evacuation, 20 locations of medical supply centers, six types of health supplies, with an emergency patient threshold of 90, and a budget limit of Rp.610,642,022. The result of optimization in the normal scenario is presented in Table 1.

Table 1. Optimization Result in Normal Condition.

Chosen Relief Shelters	**Relief Shelter Candidate Locations**	**Relief Shelter Capacity (Number of Patients)**	**Medical Supply Center Locations**
1	3	10	14
2	8	73	7
3	9	109	15
4	10	67	16
5	16	55	13
6	21	11	18
7	28	92	16
8	43	32	6
9	45	12	5
10	46	44	6
11	50	35	10
12	51	34	12
13	54	21	1
Number of Allocated Patients		595	91%
Total Number of Patients		651	100%
Total Cost		Rp.609,702,926	99.8%
Total Budget		Rp.610,642,022	100%

From these results, the model chose to open 13 medical relief shelters from 54 location candidates. Since the model has no function that limits the medical relief capacity, the allocation of patients to the medical relief shelters varies. Some of them might treat only a small number of patients, but the others might treat many patients. For instance, medical relief shelter 3 only accommodated 10 patients, while the medical relief shelter 9 had a capacity for 109 people. Thus, the range of capacities that must be prepared varies for these shelters. In the field, this can be done by setting up tents, placing cot mattresses and chairs, as well as allocating medical personnel in accordance with the number of patients.

In addition, the solution provided by the model shows that only 13 of the 20 locations of the medical supply center are used to deliver medicines and medical equipment to the relief shelters. Each relief shelter receives medical supplies from one central medical supply point, but there is a medical supply center (location 16) which is the source for two relief shelter locations. The connection between the relief shelter and the medical supply center is easier to see in Fig. 3 where the green line represents the allocation of the medical supply center to the health center.

Furthermore, the solution under normal scenario is using a budget of Rp.610,642,022 with 595 out of 651 patients could be allocated. There are still 9% of patients who cannot be allocated to a medical relief shelter due to the total cost needed to allocate all patients is greater than the total available budget. Patient allocation can be seen more clearly in Fig. 3, where the dashed blue line represents the relationship of patient allocation to the relief shelter.

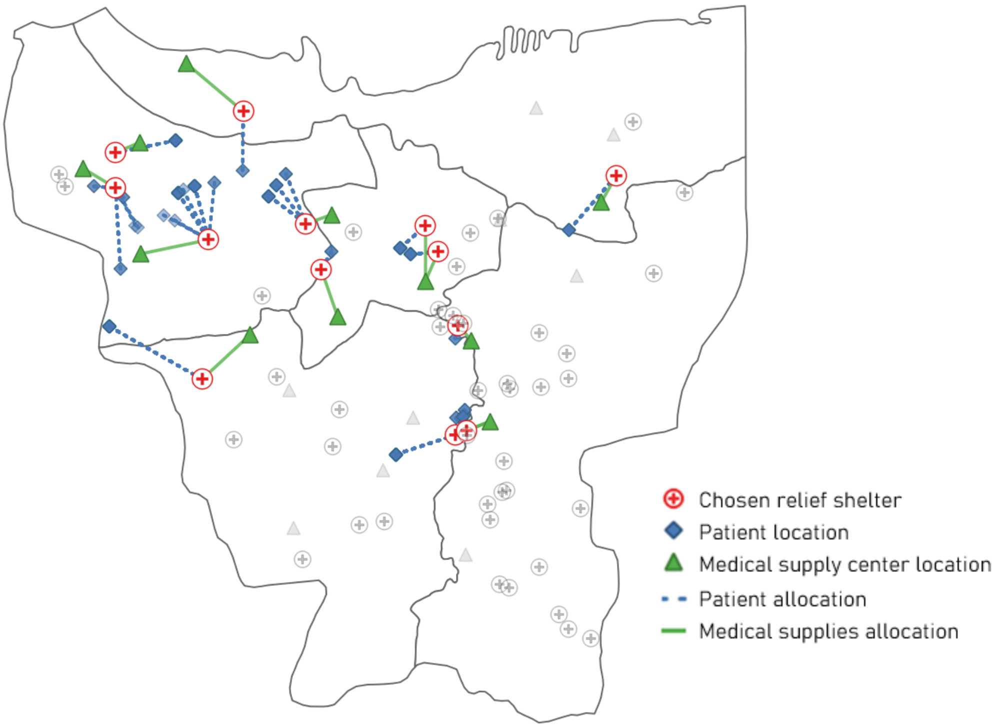

Fig. 3: Visualization of Results in Normal Condition.

In the pessimistic scenario, all data used is the same as data used in normal condition except for the amount of the budget. As explained earlier, the amount of budget used is 50% of the normal budget, which is Rp.305,321,011. The results of optimization in the pessimistic scenario can be seen in Table 2.

In pessimistic condition, the number of relief shelters selected is 10, which is less than the 13 relief shelters selected under the normal condition. This is in line with expectations because the budget in pessimistic condition is smaller than in normal condition. In addition to the number of points selected, the total capacity that needs to be prepared is also smaller than the normal condition scenario.

With the reduction in the capacity of the relief shelter, the number of allocated patients has also decreased. In this pessimistic condition, only 292 out of 651 or 45% of patients can be allocated to 10 relief shelters. It can be seen from Fig. 4 that there are some patient locations that are not allocated to any relief shelters. Although there are many patients who are not allocated, the model can still choose the locations of optimal relief shelters with the given conditions.

In the optimistic condition, the number of relief shelters given by the model is 13 points. This number is the same as in normal scenario. Although the number of shelters selected in normal and optimistic conditions are the same, the capacity in the two conditions is different. In an optimistic condition, the total capacity that must be prepared has a total of 651 people. This means that in this condition, the percentage of allocated patients reaches 100%.

Table 2. Optimization Result in Pessimistic Condition.

Chosen Relief Shelters	Relief Shelter Candidate Locations	Relief Shelter Capacity (Number of Patients)	Medical Supply Center Locations
1	8	40	7
2	9	47	15

Chosen Relief Shelters	Relief Shelter Candidate Locations	Relief Shelter Capacity (Number of Patients)	Medical Supply Center Locations
3	10	18	16
4	21	11	18
5	28	75	16
6	43	26	6
7	45	9	5
8	46	31	6
9	50	21	10
10	51	14	12
	Number of Allocated Patients	292	45%
	Total Number of Patients	651	100%
	Total Cost	Rp.305,247,297	99.98%
	Total Budget	Rp.305,321,011	100%

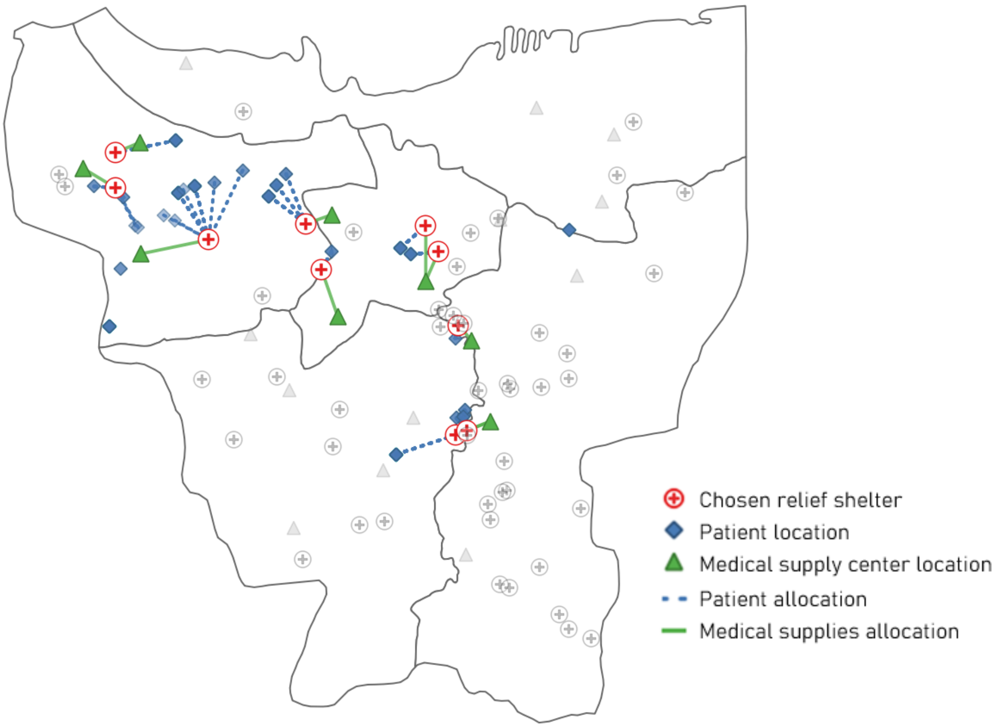

Fig. 4: Visualization of Results in Pessimistic Condition.

Like the pessimistic condition, in the optimistic condition, the data used are almost all the same as normal condition, only the amount of the budget used is 150% of the normal condition, which is Rp.915,963,033. Table 3 shows the optimization result under the optimistic scenario. Of the three scenarios used for analysis, the optimistic condition is the only scenario that has a relatively large distance between the total cost and the total budget, with the total cost being used only 72.44% of the total budget.

In addition to differences in capacity and percentage of patient allocation, there are also differences in the allocation of medical supply centers to relief shelters. It can be seen in Table 3 that medical center 1 will supply all the chosen relief shelters. This is more easily seen in the visualization of results in Fig. 5, where there is a central point of the relief shelter allocated to all selected relief shelter points.

Table 3. Optimization Result in Optimistic Condition.

Chosen Relief Shelters	Relief Shelter Candidate Locations	Relief Shelter Capacity (Number of Patients)	Medical Supply Center Locations
1	3	10	1, 14
2	8	78	1, 7
3	9	123	1, 15

Chosen Relief Shelters	Relief Shelter Candidate Locations	Relief Shelter Capacity (Number of Patients)	Medical Supply Center Locations
4	10	72	1, 16
5	16	65	1, 13
6	21	11	1
7	28	95	1, 16
8	43	32	1, 6
9	45	14	1, 5
10	46	48	1, 6
11	50	39	1, 10
12	51	41	1, 12
13	54	23	1
Number of Allocated Patients		651	100%
Total Number of Patients		651	100%
Total Cost		Rp.663,483,147	72.44%
Total Budget		Rp.915,963,033	100.00%

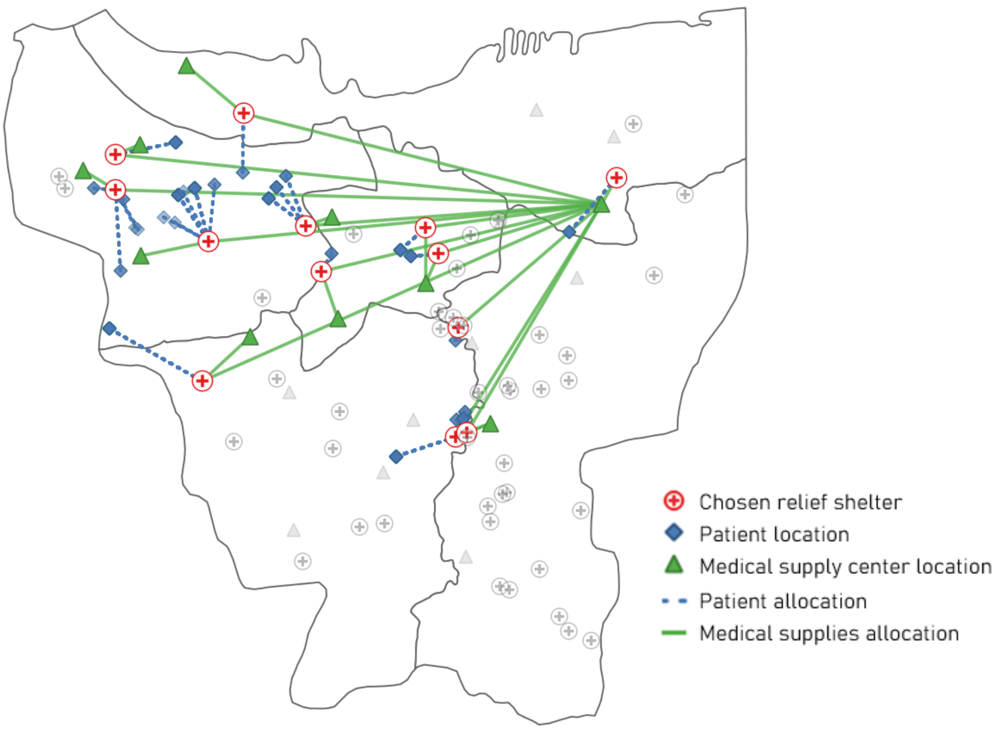

Fig. 5: Visualization of Results in Optimistic Condition.

The allocation of relief shelters looks odd at first glance because the optimal solution suggests the medical center to supply relief shelters that are quite far in distance. This is due to the optimization model considering the distance of the vehicle sending medical supplies in the form of costs, and costs are included in the constraint function, not in the objective function. If the total cost is still below the available budget, the solution will be considered valid. In this optimistic condition, because the budget is still far above the total cost, this allocation might be performed. This phenomenon can be further investigated and developed in further research, for instance by considering cluster and efficiency analysis[38].

The previous analysis was performed using the emergency patient threshold of 90. Because the severity value for all patients was given using a uniform random distribution with a minimum value of 1 and a maximum value of 100, the ratio of emergency patients was 10% of the total patients. In this section, optimization is performed on the three scenarios with different emergency patient thresholds.

In this research model, emergency patients need medical supplies at a higher cost than normal patients. With these parameters, the total cost will increase along with the increase in the ratio of emergency patients. If the budget is smaller than the total cost, then the number of patients allocated will decrease.

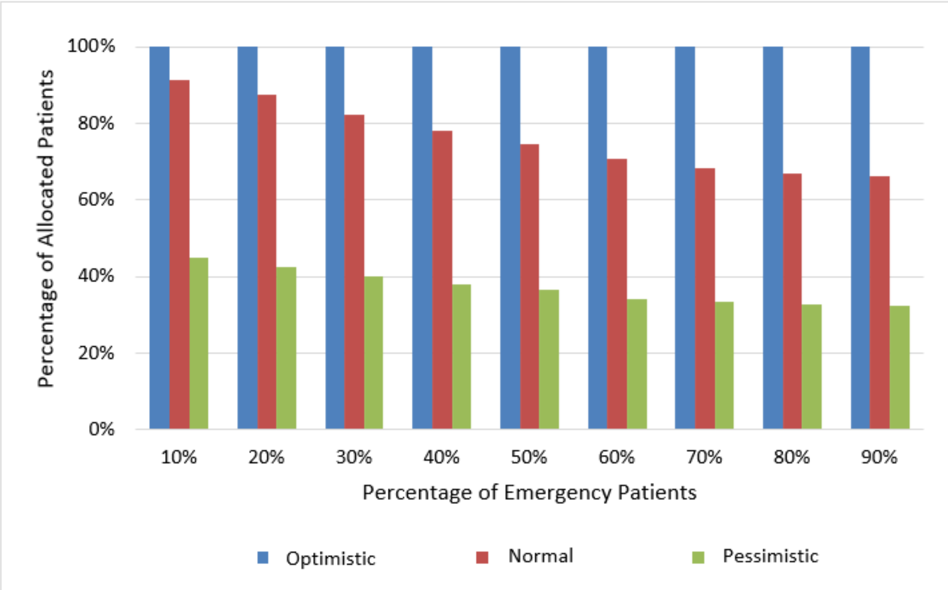

Fig. 6: Proportion of Allocated Patients based on the Number of Emergency Patients.

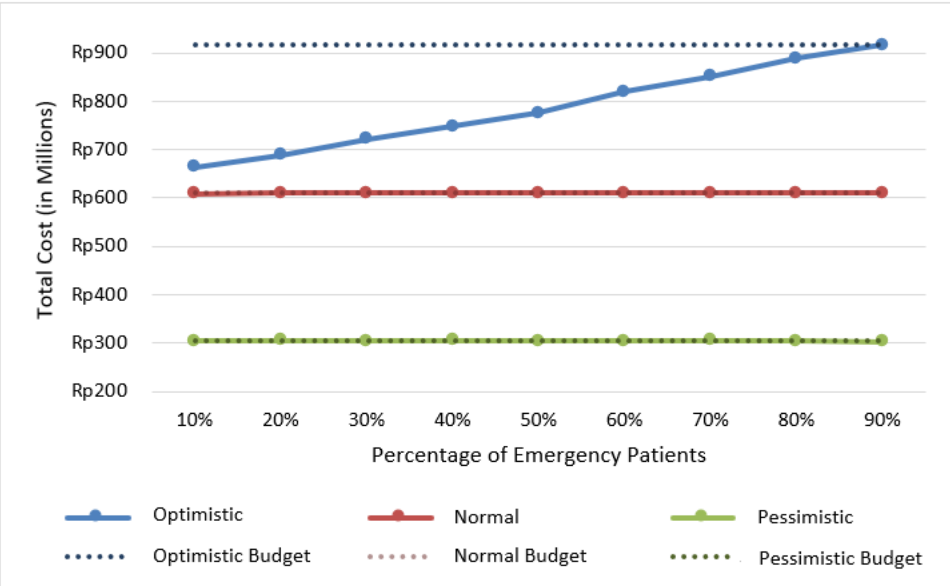

Fig. 7: Total Cost based on the Number of Emergency Patients.

The decrease in the percentage of allocated patients that occurred due to an increase in emergency patients can be seen more clearly in Fig. 6 and Fig. 7. In Fig. 6, it appears that the optimistic scenario is the only scenario that has a percentage of allocated patients by 100% in each percentage of emergency patients tested. Figure 7 reveals that this is due to the optimistic condition still has a sufficient budget for each possibility of emergency patients' proportion.

In the other two scenarios, namely normal and pessimistic conditions, the total costs always have a value that is close to the budget (as shown in Fig. 7). Because of this, it can be seen in Fig. 6 that in both scenarios, as the percentage of emergency patients increases, the percentage of allocated patients will decrease.

4. Conclusion

Natural disasters often occur in Indonesia, and Jakarta is no exception where floods is the most common disaster occur in Jakarta. In case of an emergency due to such a natural disaster, the government needs to give an immediate response to rescue all the victims. One of the critical decisions that must be promptly determined is related to the placements of the medical relief shelters. The number of medical relief shelters should be adequate and accessible for all patients. However, there is also a limited available budget in disaster relief situations. Therefore, this research uses an integer programming model to determine the optimal solution in selecting medical relief shelters in case of a natural disaster with a limited budget in Jakarta. In this research, we use three budget scenarios, which are 100% (normal condition), 50% (pessimistic condition), and 150% (optimistic condition).

Based on this research, the optimization model can be used to optimally find relief shelter locations within a certain budget. Moreover, it allows us to see the effect of the amount of budget on the percentage of allocated patients in each relief shelter. The higher amount of available budget, the more patients can be treated, even if most of them are in severe condition.

This research still has some limitations since it only focuses on selecting the best medical relief shelter locations. The optimization model used in this research does not have capacity constraint for each medical relief shelter, which causes it to generate solutions that give a high capacity in certain relief shelters and a low capacity for other shelters. Hence, for future research, it is suggested to add capacity constraint to limit the maximum number of patients that can be treated in each medical relief shelter. Moreover, the model can also be improved by considering the total distance in delivering the medical supplies from medical centers to relief shelters so that the transportation cost can be reduced. In addition, it is also recommended to explore the allocation and relocation problem of patients and healthcare workers from different relief shelters in a certain time horizon.

This research only considers whether a patient is in severity condition or not based on the threshold value. It might be enhanced by prioritizing the victims, so we will have better understanding who are urgently need to be treated.

References

1) Boonmee, C., Arimura, M., and Asada, T., "Facility location optimization model for emergency humanitarian logistics," *Int. J. Disaster Risk Reduct.*, **24**, 485-498 (2017). https://doi.org/10.1016/j.ijdrr.2017.01.017
2) Centre for Research on the Epidemiology of Disasters, "2022 Disasters in Numbers" (CRED, 2023), available at https://reliefweb.int/report/world/2022-disasters-numbers#:~:text=Executive%20Summary,totaled%20around%20US%24%20223.8%20billion. (accessed October 29, 2023)
3) Özdamar, L. and Ertem, M. A., "Models, solutions and enabling technologies in humanitarian logistics," *Eur. J. Oper. Res.*, **244**(1), 55-65 (2015). https://doi.org/10.1016/j.ejor.2014.11.030
4) Badan Pusat Statistik DKI Jakarta, "Rekapitulasi Data Banjir DKI Jakarta dan Penanggulangannya Tahun 2020" (BPS DKI Jakarta, DKI Jakarta, 2020).
5) Gu, J., Zhou, Y., Das, A., Moon, I., and Lee, G., "Medical relief shelter location problem with patient severity under a limited relief budget," *Comput. Ind. Eng.*, **125**, 720-728 (2018). https://doi.org/10.1016/j.cie.2018.03.027
6) Editorial Badan Penanggulangan Nasional Bencana, "Kepala BNPB dan Menteri Kesehatan Bahas Penanganan Banjir dan Longsor [Head of National Agency for Disaster Countermeasure (BNPB) and Minister of Health Discuss Flood and Landslide Management]" (BNPB, 2016), available at https://bnpb.go.id/berita/kepala-bnpb-dan-menteri-kesehatan-bahas-penanganan-banjir-dan-longsor (accessed July 8, 2023)
7) Klipper, I. G., Zipf, A., and Lautenbach, S., "Flood Impact Assessment on Road Network and Healthcare Access at the example of Jakarta, Indonesia," *AGILE-GISS*, **2**, 1–11 (2021). https://doi.org/10.5194/agile-giss-2-4-2021
8) Widayatun, W. and Fatoni, Z., "Permasalahan Kesehatan dalam Kondisi Bencana: Peran Petugas Kesehatan dan Partisipasi Masyarakat [Health Problems in a Disaster Situation: The Role of Health Personnels and Community Participation]," *Jurnal Kependudukan Indonesia*, (2013). https://doi.org/10.14203/jki.v8i1.21
9) Badan Pengelola Keuangan Daerah, "Data APBD Provinsi DKI Jakarta Tahun 2019 [Jakarta Provincial Budget Data for 2019]" (DKI Jakarta, Indonesia, 2019).
10) Badan Pengelola Keuangan Daerah DKI Jakarta, "Data APBD Provinsi DKI Jakarta Tahun 2020 [Jakarta Provincial Budget Data for 2020]" (DKI Jakarta, Indonesia, 2020).
11) Habib, M. S., Lee, Y. H., and Memon, M. S., "Mathematical Models in Humanitarian Supply ChainManagement: A Systematic Literature Review," *Math. Probl. Eng.*, **2016**(1), 3212095 (2016). https://doi.org/10.1155/2016/3212095
12) Kovács, G. and Spens, K. M., "Humanitarian logistics in disaster relief operations," *Int. J. Phys. Distrib. Logist. Manag.*, **37**(2), 99-114 (2007). https://doi.org/10.1108/09600030710734820
13) Berawi, M. A., Siahaan, S. A. O., Gunawan, Miraj, P., and Leviakangas, P., "Determining the Prioritized Victim of Earthquake Disaster Using Fuzzy Logic and Decision Tree Approach," *Evergreen*, **7**(2), 246-252 (2020). https://doi.org/10.5109/4055227
14) Kumalawati, R., Yuliarti, A., Anggraeni, R. N., and Murliawan, K. H., "The Potential Mapping of Land Fire Using SNPP VIIRS as a Basis for Environmental Damage Mitigation," *Evergreen*, **8**(3), 524-534 (2021). https://doi.org/10.5109/4491638
15) Surjono, S., Wardhani, D. K., Yudono, A., and Muluk, M. R. K., "Residential Preferences of Post Great Disaster in Palu City, Indonesia," *Evergreen*, **8**(4), 706-716 (2021). https://doi.org/10.5109/4742114
16) İlhan, A., "The Humanitarian Relief Chain," *South East Eur. J. Econ. Bus.*, **6**(2), 45-54 (2011).

https://doi.org/10.2478/v10033-011-0015-x

17) Trivedi, A. and Singh, A., "Facility location in humanitarian relief: a review," *Int. J. Emergency Management*, **14**(3), 213-232 (2018). http://doi.org/10.1504/IJEM.2018.094235
18) Dekle, J., Lavieri, M. S., Martin, E., Emir-Farinas, H., and Francis, R. L., "A Florida county locates disaster recovery centers," *Interfaces*, **35**(2), 133-139 (2005). http://doi.org/10.1287/inte.1050.0127
19) Hale, T. and Moberg, C. R., "Improving supply chain disaster preparedness: a decision process for secure site location," *Int. J. Phys. Distrib. Logist. Manag.*, **35**(3), 195-207 (2005). http://doi.org/10.1108/09600030510594576
20) Kongsomsaksakul, S., Yang, C., and Chen, A., "Shelter location-allocation model for flood evacuation planning," *J. East. Asia Soc. Transp. Stud.* **6**, 4237-4252 (2005). https://doi.org/10.11175/easts.6.4237
21) Balcik, B. and Beamon, B. M., "Facility location in humanitarian relief," *Int. J. Logist.*, **11**(2), 101-121 (2008). https://doi.org/10.1080/13675560701561789
22) Paul, J. A. and Batta, R., "Models for hospital location and capacity allocation for an area prone to natural disasters," *Int. J. of Oper. Res.*, **3**(5), 473-496 (2008). https://doi.org/10.1504/IJOR.2008.019170
23) Ablanedo-Rosas, J. H., Gao, H., Alidaee, B. and Teng, W. Y., "Allocation of emergency and recovery centres in hidalgo, Mexico," *Int. J. of Serv. Sci.*, **2**(2), 206-218 (2009). https://doi.org/10.1504/IJSSci.2009.024941
24) Horner, M., and Downs, J., "Optimizing hurricane disaster relief goods distribution: model development and application with respect to planning strategies," *Disasters*, **34**(3), 822-844 (2010). https://doi.org/10.1111/j.1467-7717.2010.01171.x
25) Mete, H. O. and Zabinsky, Z. B., "Stochastic optimization of medical supply location and distribution in disaster management," *Int. J. Prod. Econ.*, **126**(1), 76–84 (2010). https://doi.org/10.1016/j.ijpe.2009.10.004
26) Zhu, J., Liu, D., Huang, J., and Han, J., "Determining storage locations and capacities for emergency response," *The Ninth International Symposium on Operations Research and Its Applications* (ISORA'10), August, Chengdu-Jiuzhaigou, China (2010).
27) Jabbarzadeh, A., Fahimnia, B., and Seuring, S., "Dynamic supply chain network design for the supply of blood in disasters: a robust model with real world application," *Transp. Res. Part E: Logist. Transp. Rev.*, **70**, 225-244 (2014). https://doi.org/10.1016/j.tre.2014.06.003
28) Bayram, V., Tansel, B. Ç., and Yaman, H., "Compromising system and user interests in shelter location and evacuation planning," *Transp. Res. Part B: Methodol.*, **72**, 146-163 (2015). https://doi.org/10.1016/j.trb.2014.11.010
29) Kılcı, F., Kara, B. Y., and Bozkaya, B., "Locating temporary shelter areas after an earthquake: A case for Turkey," *Eur. J. Oper. Res.*, **243**(1), 323-332 (2015). https://doi.org/10.1016/j.ejor.2014.11.035
30) Salman, F. S. and Yücel, E., "Emergency facility location under random network damage: insights from the Istanbul case," *Comput. Oper. Res.*, **62**, 266-281 (2015). https://doi.org/10.1016/j.cor.2014.07.015
31) Marcelin, J. M., Horner, M. W., Ozguven, E. E., and Kocatepe, A., "How does accessibility to post-disaster relief compare between the aging and the general population? A spatial network optimization analysis of hurricane relief facility locations," *Int. J. Disaster Risk Reduct.*, **15**, 61-72 (2016). https://doi.org/10.1016/j.ijdrr.2015.12.006
32) Stienen, V. F., Wagenaar, J. C., den Hertog, D., and Fleuren, H. A., "Optimal depot locations for humanitarian logistics service providers using robust optimization," *Omega*, **104**, 102494 (2021). https://doi.org/10.1016/j.omega.2021.102494
33) Yassin, I. A., Patrisina, R., and Amrina, E., "Location-Allocation Model for Victims and Health Workers during Post Earthquake-Tsunami Health Crisis in Padang City," *Evergreen*, **9**(1), 234-245 (2022). https://doi.org/10.5109/4774244
34) Farahani, R. and Hekmatfar, M., "Facility Location Concepts, Models, Algorithms and Case Studies," Springer, Berlin, (2009). https://doi.org/10.1007/978-3-7908-2151-2
35) Dönmez, Z., Kara, B. Y., Karsu, O., and Saldanha-da-Gama, F., "Humanitarian facility location under uncertainty: Critical review and future prospects," *Omega*, **102**, 102393 (2021). https://doi.org/10.1016/j.omega.2021.102393
36) Hillier, F. S. and Lieberman, G. J., *Introduction to Operations Research*, 9th ed., McGraw-Hill, New York (2010).
37) Singh, P., Pasha, J., Moses, R., Sobanjo, J., Ozguven, E. E., and Dulebenets, M. A., "Development of exact and heuristic optimization methods for safety improvement projects at level crossings under conflicting objective," *Reliab. Eng. Syst. Saf.*, **220**, 108296 (2022). https://doi.org/10.1016/j.ress.2021.108296
38) Surjandari, I., Rindrasari, R., and Dhini, A., "Evaluation of Efficiency in Logistics Company: An Analysis of Last-Mile Delivery," *Evergreen*, **10**(2), 649-657 (2023). https://doi.org/10.5109/6792811