



Mobile Clinics: Medical Service Strategy for Disaster Healthcare Response Operation

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Abstract:

Purpose: Healthcare facilities disrupted due to disasters leave affected communities without access to sufficient health care. This study proposes the use of mobile health clinics (MHCs) to address the issues faced by medical service providers during disaster response.

Design/methodology/approach: An MHC is a mobile facility that provides healthcare services from a stationary location. The model was developed as a healthcare response strategy that considers demand uncertainties due to the nature of the disaster. Therefore, the objective of this study is to generate an MHC route and schedule simultaneously and determine how each MHC meets patient demands within a prespecified time horizon. A stochastic model is presented because the impact of a disaster varies according to its scale.

Findings: An investigation of medical shelters in locations with high numbers of displaced people and the routing of mobile clinics for several facility locations with a small number of people showed that a hybrid strategy comprising a medical shelter and MHC is the best option. MHCs can serve many locations within walking distance. They can also be routed to other locations when time constraints allow. When a large number of people are in a shelter, building a medical facility provides better service.

Originality/value: This study proposed MHCs as a medical service strategy to address the challenges faced by communities during disaster responses. The aim of MHCs is to improve communities' access to healthcare services.

Keywords: mobile health clinics, disaster response, healthcare, routing

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1. Introduction

According to the World Health Organization (WHO), emergencies tend to disrupt daily activities, leading to suffering and discomfort. Extra efforts and measures need to be adopted to handle any form of challenge in such

circumstances (World Health Organization, 2007). However, these challenges affect immediate relief supplies, such as tents, food, water, or daily needs, and have a higher intensity in the health sector. They can cause medical disabilities, as hospitals need to treat many people simultaneously, while others need to wait in their shelters. The provision or rendering of this service during a disaster is difficult for healthcare providers. These difficulties vary from limited resources and medical kits to various illnesses that last indefinitely (Pourhosseini, Ardalan & Mehrolohasani, 2015).

Disasters often result in ill-health and death, either directly or through the disruption of health systems. This also occurs because of a lack of access to healthcare services in the affected area. The health impact of disasters is minimized when local responders such as Emergency Medical Services, firefighters, police, Search and Rescue teams, and national agencies are adequately established (World Health Organization, 2007). Disasters also affect local responders, as they are part of the affected area. Hospitals are burdened by many people simultaneously, while others must wait in their shelters to receive medical intervention. Some communities render medical services as a form of disaster response because health facilities are disrupted, while local responders are stunned by the scale of the disaster. Providing these services in such circumstances is perceived as a difficult task by healthcare providers. This varies from limited resources and medical kits to illnesses that last for an undefined period. With hospitals and clinics focusing on emergency patients, some people might not receive treatment because of the non-availability of certain services. Some major healthcare logistics issues must be addressed wisely during such events. Adopting a proper logistics strategy improves medical assistance in the event of such events, aside from the availability of adequately trained personnel and well-prepared staff.

The importance of healthcare organizations remaining functional, specifically hospitals, extends beyond the necessity to sustain and render continuous medical services for the community in the aftershock of a disaster. Some countries have specifically developed disaster medical teams (DMTs) to provide treatment in affected areas during the initial phase of a disaster to lessen the burden on local responders. Arziman (2015) stated some examples of DMTs in some nations, such as the United States (Disaster Medical Assistance Team), Canada (Disaster Assistance Response Team), Japan (Japan Disaster Medical Assistance Team), Israel (military), and Turkey (National Medical Rescue Team). Apart from this, other medical-related organizations such as the WHO, the International Federation of Red Cross and Red Crescent Societies, or Doctors Without Borders are often involved in huge disaster cases. Furthermore, additional portable and temporary healthcare facilities are sometimes used under such circumstances. These portable healthcare facilities include tents, floating hospitals (ships), flying hospitals (airplanes), and mobile hospitals (Bitterman & Zimmer, 2018). Unfortunately, research in the healthcare field focuses more on descriptive analysis and qualitative approaches to create credible data about critical challenges in medicine and healthcare (Renjith, Yesodharan, Noronha, Ladd & George, 2021). In addition to the availability of sufficiently educated and prepared people, implementing an effective logistics plan increases medical aid in the aftermath of disasters. System improvements can be done as part of the preparedness stage for disasters in the healthcare context. Optimization may be used to enhance the distribution and supply of healthcare professionals to increase service coverage, decrease patient travel requirements, increase facility capacity, and maximize health or access equity (Wang, 2012). This study proposes mobile health clinics (MHCs) as a medical service strategy to curb the challenges encountered during disasters. The aim of mobile health clinics (MHC) is to ensure that healthcare services are accessible to those affected as some communities rely on mobile clinic teams during disasters when road accessibility is limited or when health facilities need to be reestablished. MHC targets non-emergency patients who face medical care challenges and provides medical services including immunizations for people with constant health needs while ensuring that they are not disrupted. The developed model is perceived as a healthcare strategy considering the demand uncertainties that arise due to the nature of the disaster. Its objective is to simultaneously generate routes and schedules while determining how each mobile health clinic covers patient demands within a prespecified time horizon. A stochastic model is presented based on the varying impact of a disaster according to its scale.

2. Literature Review

Mobile clinics aim to ensure that healthcare services reach the targeted population and improve accessibility (Malone, Williams, Smith-Fawzi, Bennet, Hill, Katz et al., 2020). Globally, they were developed for areas with limited or no access to medical services. Affected communities rely on mobile clinic teams during flooding or

earthquakes, when road accessibility is limited, or health facilities are being reestablished. They help diagnose and refer patients to medical centers, attend to non-emergency patients, follow-up on patients, and dispense medicines to those cut off from their supply. The number of patients served at one location was proportional to the duration of the mobile clinic. Table 1 shows a typical example of MHC implementation during the disaster response phase.

Authors	Location	Type of Disaster	Type of Service
Weiss, Weiss, Teeter & Geraci (1999)	Northridge US	Earthquake	Respiratory and ear infections, minor injuries, vaccinations
Krol, Redlener, Shapiro & Wajnberg (2007)	Mississippi US	Hurricane	Common respiratory and skin diseases, minor injuries, vaccinations, medical care for chronic conditions
Ahmad, Mohamad, Mohd, Mohamad, Saharudin, Hamzah et al. (2008)	Johor, Malaysia	Flood	Upper respiratory tract infections, musculoskeletal problems, medical care for chronic conditions
Chan & Kim (2010)	Kashmir, Pakistan	Earthquake	Earthquake-related trauma, wounds, and gastrointestinal infections
Levine & Shetty (2012)	Libya	Civil war	Blast and burn injuries, wounds from gunshots, medical care for specific illnesses
World Health Organization (2013)	Jakarta, Indonesia	Flood	Diarrhea, respiratory diseases, medical care for some illnesses
Rassekh, Shu., Santosham, Burnham & Doocy (2014)	Aceh, Indonesia	Earthquake and Tsunami	Emergency surgeries, head trauma, diarrhea, respiratory diseases, minor injuries, vaccinations, medical care for chronic conditions
Cheng, Shi, Du, Hu., Feng, Huang et al. (2015)	Sichuan, China	Earthquake	Emergency surgeries and head trauma
Leibowitz, Livaditis, Daftary, Pelton-Cairns, Regis & Taveras (2021)	Boston, USA	Pandemic Covid-19	Preventive pediatric clinical services
Shukla, Fressin, Un, Coetzer & Chaguturu (2021)	USA	Pandemic Covid-19	Covid-19 Vaccinations

Table 1. Mobile Health Clinic Implementations during Disaster Responses

The essence of the MHC concept is to eliminate certain barriers encountered by healthcare providers and patients, such as distance, geographical difficulties, extensive waiting times, and accessibility. However, several logistical challenges limit their utilization. First, finding suitable locations for MHC operations is complicated. They need to be easily accessed by the patients. Therefore, yards, fields, schools, and community centers near evacuation areas are ideal. Haley and Cone (2016) state that certain geographical conditions in the affected region hinder some operations. Second, because there are limited MHCs available and disaster victims are abundant, their allocations to serve several locations is challenging (Leibowitz et al., 2021). Third, with restricted working hours for medical personnel, e.g. paramedics, nurses, and doctors, the routing sequences and schedules need to be optimized to maximize the number of patients treated at each location (Shukla et al., 2021). Medical personnel tend to be scarce during disaster responses, as many are pulled to more prominent hospitals to treat severely injured persons (Leibowitz et al., 2021; Shukla et al., 2021). Lastly, the numbers of patients and disease types are uncertain (Haley & Cone, 2016; Ahmad et al., 2008; Krol et al., 2007). Irrespective of the fact that the number of victims is estimated after a quick assessment, an actual figure is usually difficult to predict. A disaster environment worsens refugees' conditions, and disease occurs after some period. Furthermore, as medical treatment is independent of each patient, the estimated time for treatment is uncertain.

The concept of the mobile facility routing problem (MFRP) was introduced by Halper and Raghavan (2011) to provide adequate services in a large region. They are expected to relocate to other locations once the demand has been served. This study presents deterministic MFRPs to maximize the number of demands covered. However,

these are different from the issues associated with vehicle routing, and the mobile facility serves these demands based on the extent of services rendered. It has many application domains, including cellular telephone coverage, postal facilities (Department of Transportation United Kingdom, 2009; Hong Kong Post, 2008), and healthcare-related services (Alexy & Elnitsky, 1996). Halper and Raghavan (2011) also reported that the Maximal Covering Location Problem is a special case of the MFRP with a constant demand rate and a non-relocated facility. The MFRP is an NP-hard problem with two types of heuristics used to solve single and multiple mobile facility routing issues.

Doerner, Focke and Gutjahr (2007) realized the need to improve healthcare services in developing countries and proposed a single mobile healthcare facility using a location routing model. The route for mobile healthcare facilities depends on the number of available working hours in a given period. There are three main criteria: economic efficiency (weighted average number of tour stops \times tour duration), p-median (average distances between tour stops), and coverage (% of people able to reach tour stops within a given maximum distance). Lei, Lin and Miao (2014, 2016) addressed the mobile facility routing and scheduling issue with stochastic demand, which optimized the route and timetable of a fleet of mobile facilities serving consumers with variable demand while minimizing the overall cost. Bayraktar, Günneç, Salman and Yücel (2021) described a multiperiod facility placement issue with mobile facilities and the demand for delivering aid to enroute refugees. During each period, refugees move from one node to another by joining and departing the network at various times. Each facility served refugees at a certain node during each period. The challenge is to deploy mobile facilities in each period while guaranteeing that the service requirements are fulfilled. In addition, a mobile facility location problem has been studied previously by Halper, Raghavan and Sahin (2015), Raghavan, Sahin and Salman (2019), and Feldkord, Knollmann and Heide (2022).

Although the concept of a mobile facility is not new, the most relevant study considering uncertainty is limited to those carried out by Lei et al. (2014, 2016). The mobile health clinic operation was modeled by adopting the concept of the routing problem, its capacity, and time constraints. The model adopted in this study was previously used for MFRPs, similar to the concept of MHCs. Furthermore, some uncertain aspects and stochastic demands were considered.

3. MHC Routing Problem

The MFRP was employed to model disaster response operations. MHCs are facilities that can only render certain services when they are stationary. The model was developed as a strategic plan or preparedness for medical service providers concerning demand uncertainties. It is usually challenging to accurately predict the number of people evacuated during a disaster. Uncertainties in the number of patients are presented in this study as a stochastic MFRP. Irrespective of the fact that a set of probability distribution functions is used to characterize this demand, in practice, it is often difficult for each customer. This study employed prespecified scenarios associated with the probability of capturing different demand patterns.

The objective of this model is to ensure that the MHC route covers as many patients as possible in a prespecified time horizon. According to Lei, Lin, Miao and Qi (2013) and Lei et al. (2016), there are three critical features relating to the mobile facility problem that needs to be considered, and these include:

1. The medical equipment and healthcare-related goods are mounted on vehicles,
2. The travel time of MHCs needs to be explicitly accounted for in the model,
3. The number of patients to be served at a location is proportional to the duration of stay.

The aim is to determine the service sequences of MHCs related to a planning phase to cover the demands of some prespecified regions at a minimum cost. The fixed operating costs associated with each mobile health clinic used in the system include the following:

1. The cost of allocating MHCs and assigning the patients to a certain location,
2. The routing cost to move MHCs from one location to another,

3. The expected cost of unmet demand due to some patients or time limitations.

As shown in Figure 1, a single-depot mobile clinic routing problem was considered. This is because although mobile clinics are operated in more than one health facility and by different organizations, the coordination system is better reflected by the single-depot assumption. Although the adopted routing strategy is essential, this study failed to focus on how coordination ensues.

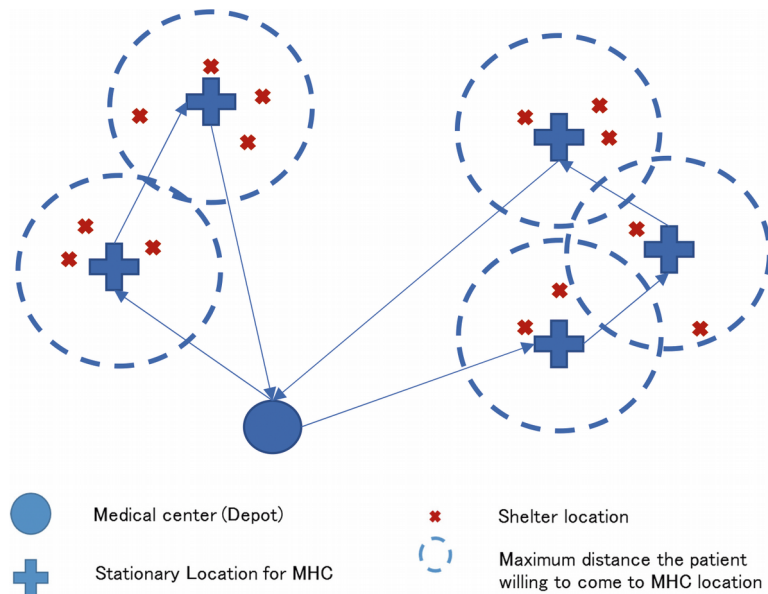


Figure 1. Mobile Health Clinic Routing Illustration

Assumptions and limitations:

Several assumptions and limitations were postulated to facilitate mathematical formulation.

- a) The planning horizon prespecified a discrete number with an identical length (one working day).
- b) Demand is independent, nonstationary, and stochastic with respect to time.
- c) There is a limit to the capacity of each MHC in the form of the maximum service rate.
- d) Its service level depends on the distance between the customer and the MHC parking location.
- e) A substantial penalty cost is imposed on untreated patients.

Mathematical Formulation:

Let the undirected graph $G = (N, \mathcal{A})$, where $N = \{0, 1, 2, \dots, n\}$ and $\mathcal{A} = \{(i,j): i,j \in N\}$ are sets of nodes and links, respectively. Subsets $P \subseteq N$ and $L \subseteq N$ are sets of patient nodes and mobile clinic locations, respectively.

Sets, indices, and parameters:

H	The length of the time horizon
N	A set of nodes, $N = \{0, 1, 2, \dots, n\}$
P	The set of all patient demand nodes, $(i \in P) \subseteq N$
J	The set of nodes where the mobile clinics are located $(j \in J) \subseteq N$
K	A set of available mobile clinic $k = \{1, 2, \dots, K\}$
Z	Set of scenarios $\zeta \in Z$
t_{ij}	Travel time from node j to i

d_{ij}	Distance (km) between the patient's location to where the mobile clinic is stationed
α	Assigning patient cost (USD) per unit distance
β	Penalty cost (USD) per unit of untreated patients
γ	Transportation cost (USD) for each mobile clinic
$w_i^h(\zeta)$	Patient needs to be treated at location i in period h for scenario ζ
$Prob(\zeta)$	Probability for scenario ζ occurrence
Cap	The capacity of the mobile clinics

However, the objective function consists of two parts: minimizing the operational cost (cost of fetching mobile clinics) and minimizing the cost due to unmet demand, which led to the adoption of two-stage stochastic programming. The mathematical models for these are as follows:

First stage:

The first stage consists of the decision to operate mobile clinics and where they need to be stationed. The decision was made before the scenario was realized. The decision variables are as follows:

$$y_k = \begin{cases} 1 & \text{if MHC } k \text{ is allowed to be used} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

$$x_{jkh} = \begin{cases} 1 & \text{if MHC } k \text{ is located at location } j \text{ at period } h \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

Second stage:

In the second stage, decisions relating to recourse actions are based on the first, which involves different scenarios ζ . The decision variable for this phase is $z_{ijk}^h(\zeta)$ defined as the number of patients in shelter i being served by MHC k . In addition, $m_h(\zeta)$ is the total number of patients not served in period h . This stage aims to minimize the cost associated with demand satisfaction, including those assigned and the penalty for unmet demands. The problem is stated as follows:

$$Q(x, \zeta) = \min \sum_i^P \sum_j^J \sum_k^K \sum_h^H \alpha d_{ij} z_{ijk}^h(\zeta) + \beta \sum_h^H m_h(\zeta) \quad (3)$$

Subject to:

$$\sum_j^J \sum_k^K z_{ijk}^h(\zeta) \leq w_i^h(\zeta), \forall i, h \quad (4)$$

$$\sum_i^P z_{ijk}^h(\zeta) \leq Cap x_{jkh}, \forall j, k, h \quad (5)$$

$$\sum_i^P \sum_j^J \sum_k^K z_{ijk}^h(\zeta) + m_h(\zeta) \geq \sum_i^P w_i^h(\zeta), \forall h \quad (6)$$

$$x_{jkh} + x_{j'kh} \leq y_k, \forall h, k, j, j', j \neq j', h' \in \{h, \dots, \min\{h + t_{jj'}, |H|\}\} \quad (7)$$

$$z_{ijk}^h(\zeta) \geq 0, \forall i, j, k, h, \quad (8)$$

$$m_h(\zeta) \geq 0, \forall h \quad (9)$$

Constraint (4) ensures that the number of patients served within the stipulated time does not exceed the total number of those who need medical treatment from an MHC within the same time period. Constraint (5) states the MHC capacity restriction. Constraint (6) ensures that all demands must be met or are subject to penalty. As an MHC only provides medical services when it is stationary, Constraint (7) ensures that they perform their functions in location j and are only able to serve the next location after it travels to j' before the time horizon elapses. Constraints (8) and (9) are non-negative requirements for decision variables related to the number of patients served and unmet demands.

The two-stage stochastic programming formulation is expressed as follows:

$$\min \sum_k^K \gamma y_k + \phi(x) \tag{10}$$

Subject to: Constraints (1), (2), (7). where $\phi(x) = \min E_\zeta [Q(x,\zeta)]$, which is defined as the expected recourse function of the second-stage decision given that x is the decision made in the first stage.

4. Solution Methodology

This scenario was adopted based on stochastic demand, which was prespecified to capture different patterns. It was selected because data for the probability distribution function are usually unavailable during an emergency. Furthermore, considering all probability distribution types directly results in numerous solution spaces. A set of scenarios for different demands associated with a prespecified occurrence probability was proposed to overcome this challenge. Given the limited number, the previously stated mathematical formulation was transformed into a mixed-integer programming issue, often referred to as the deterministic equivalent problem (DEP).

Objective:

$$\min \sum_k^K \gamma y_k + \sum_\zeta^Z Prob(\zeta) \left(\sum_i^P \sum_j^J \sum_k^K \sum_h^H \alpha d_{ij} z_{ijk}^h(\zeta) + \beta \sum_h^H m_h(\zeta) \right) \tag{11}$$

Constraints:

$$\sum_j^J \sum_k^K z_{ijk}^h(\zeta) \leq w_i^h(\zeta), \forall i, h, \zeta \tag{12}$$

$$\sum_i^P z_{ijk}^h(\zeta) \leq Cap x_{jkh}, \forall j, k, h, \zeta \tag{13}$$

$$\sum_i^P \sum_j^J \sum_k^K z_{ijk}^h(\zeta) + m_h(\zeta) \geq \sum_i^P w_i^h(\zeta), \forall h, \zeta \tag{14}$$

$$x_{jkh} + x_{j'kh'} \leq y_k, \forall h, k, j, j', j \neq j', h' \in \{h, \dots, \min\{h + t_{jj'}, |H|\}\} \tag{15}$$

$$y_k, x_{jkh} \in \{0,1\} \tag{16}$$

$$z_{ijk}^h(\zeta) \geq 0, \quad \forall i, j, k, h, \zeta \tag{17}$$

$$m_h(\zeta) \geq 0, \quad \forall h, \zeta \tag{18}$$

Objective Function (11) aims to minimize the cost of using MHCs and assigns patients to the facility during the planning phase and penalty for the inability to treat them. Constraint (12) ensures that patients served do not exceed the overall medical treatment within the stipulated period. Constraints (13) and (14) state the capacity

restriction of the MHC and the inability to treat patients, unless the facility is stationed at a particular location within a specified period. Constraint (15) ensures that all the demands are met or subject to a penalty. As an MHC only renders medical services when it is stationary, this constraint ensures that it is able to execute its duties in location j and only serves the next location after it travels to j' before the time horizon elapses. Constraint (16) is a decision variable concerning the number of MHCs to be used, and when and where to locate them. Constraints (17) and (18) are non-negative requirements for decision variables related to the number of patients served as well as unmet demand.

In addition to the original model, this study added constraint (19) to ensure that the maximum number of MHCs used was less than the available number of vehicles, M_k . To ascertain that an MHC only renders its service within the intended time horizon, the working hours (horizon H) were constrained to 10 h, with a fixed service time π for all patients (20). It is evident that certain considerations were practically made by adding Constraints (19) and (20), owing to limited resources and working hours.

$$\sum_k^K y_k(\zeta) \leq M_k \quad \forall i, j, \zeta \tag{19}$$

$$\sum_j^J \sum_{j', j \neq j'}^J \sum_k^K t_{jj'} x_{jkh} + \sum_i^P \sum_j^J \sum_k^K z_{ijk}^h(\zeta) \pi w_i(\zeta) \leq H \quad \forall \zeta \tag{20}$$

These uncertainties are approximated by a finite set of realizations or scenarios Z , representing the probability distribution of the historical data of disaster occurrence and its impacts. Each scenario ζ has a probability of occurrence $\pi(\zeta)$ such that $\pi(\zeta) > 0$ and $\sum_{\zeta \in Z} \pi(\zeta) = 1$ hold, such as that derived from the flood emergency in Jakarta from 2013 to 2016. The number of mobile clinics operated is fixed compared with that of displaced persons, which increases with more significant flood scenarios. In addition, the generated method was proposed by Moreno, Alem & Ferreira (2016), who estimated the disaster occurrence using historical data and categorized it based on the scale and impact, and then calculated the probability using the bootstrap method (Efron, 1979). The demand associated with each scenario is also calculated.

5. Results and Discussion

5.1. Numerical Example and Analysis

The candidate locations for mobile clinics were assumed to be the same as those for shelters. First, it was assumed that $J \in I$ and the relationship between mobile clinic candidate locations and the shelters were $|J| = \lambda |I|$, $\lambda \in (0, 1]$, with λ set as 1. As the available data are only the number of displaced people and shelters, the number of patients for each location i is equal to:

$$r_i = \mu * ref_i \tag{21}$$

r_i denotes the number of people with medical service needs in shelter i , ref_i is the number of displaced persons in shelter i ; and lastly, μ denotes the proportion of those with medical and healthcare needs. For this numerical example, $\mu = 0.1$, with ref_i set according to the average number of displaced people in the study location, based on historical data. The capacity of each running MHC was set to 50. The assigning cost per unit distance and person is equal to \$1, while the penalty for untreated patients is \$100 per person, and the vehicle cost is \$1,500, respectively. The medical care duration was fixed at 10 min for all patients. A high penalty rate for untreated patients was imposed, and in cases where the number of sick persons exceeded the mobile clinic's capacity, an additional one was dispatched to the same location to meet these demands. Table 2 lists the probability of occurrence for each scenario.

Mathematical formulation was coded using Microsoft Visual Studio C++ 2015. It was further solved using the CPLEX 12.8 solver running on a PC with an Intel Core i7-5500U processor and 8 GB of RAM

Each scenario was solved before the DEP model was implemented, as shown in Table 3. Based on the results, the locations selected from the independent and stochastic scenarios had a relatively high number of people in each shelter. Three locations were selected for all the scenarios. Although the mathematical formulation only allowed a

maximum of one vehicle for each location, it was realized that in Scenario 1, the number of displaced people in some shelters increased significantly. The dispatch of only one vehicle results in a high number of unmet needs. In this case, the input dataset was modified, and the location of the shelters was duplicated into different nodes, and the displaced people were equally divided. Therefore, the vehicles that were dispatched to Locations 1 and 7 were counted to be more than 1.

Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Probability	0.368	0.315	0.157	0.086	0.074
Shelters	Number of displaced people				
1	378	1,134	1,750	2,059	2,367
2	78	231	328	492	492
3	30	89	138	175	176
4	23	69	108	136	137
5	29	85	132	167	168
6	125	375	398	497	497
7	151	453	709	898	905
8	9	26	40	51	51
9	21	63	98	124	125
10	23	68	106	134	135

Table 2. Occurrence probability of each scenario

Scenario	Parameters		Total Cost (USD)	Number of Mobile Clinics Dispatched	Expected Number of Unmet Needs	Location Selected
	$ I $	Number of Patients Range				
1	10	9~378	3,535.5	3	0	1, 5, 7
2	10	26~1134	9,253.5	6	0	1, 2, 5, 6, 7
3	10	40~1750	11,007.0	7	0	1, 2, 5, 6, 7
4	10	51~2059	15,225.0	10	0	1, 2, 3, 5, 6, 7
5	10	51~2367	18,225.0	10	30	1, 2, 3, 5, 6, 7
DEP	10	9~2367	17,335.5	7	66	1, 2, 5, 6, 7

Table 3. Computational Results for Jakarta Flood Data Sets

The computational results in Table 3 suggest the use of an additional number of mobile clinics, in proportion to the scale of the disaster. Although the cost associated with patient coverage is less than the vehicle cost and penalty cost, some studies have suggested that the advisable walking distance to temporary facilities during a disaster is 5-10 min (Wei, Li, Li, Liu & Cheng, 2012), which is equal to 500-1,000 m distance with the assumption that the walking speed is 4.8 km/hour. Unfortunately, with a limited number of mobile clinics, some patients, based on the computational results, are expected to walk up to 1,500 m, which is considered too far. With the additional mobile clinics covering the area, the walking distance decreased, with an average walking distance of 220 m. However, this result is still acceptable if the advisable walking distance follows the study of Doerner et al. (2007) with an upper bound of 8 km and an average distance of 2 km. In reality, some of these patients might also use certain modes of transportation, which would shorten the time needed to reach mobile clinic locations.

The results also suggest how pre-disaster decisions regarding locations affect the number of people treated during the response phase. Positioning mobile clinics to serve several shelters resulted in cost minimization, thereby

reducing the number of untreated patients. Based on the DEP result, the optimal number of dispatched MHCs is seven, which is less than the available MHCs. Therefore, based on these experimental results, it is necessary to limit mobile clinic operations. This analysis was carried out as practical reason because few organizations that were ready to dispatch mobile clinics probably could not dispatch all their resources due to budget limitations. A sensitivity analysis based on the worst-case scenario was conducted to understand the relationship between the number of mobile clinics and the related costs. The results of the analysis are shown in Figure 2. It was observed that while the number of mobile clinics was limited, the number of untreated patients was enormous, which led to an occasional higher total cost. However, when there were more than seven, the vehicle operational cost increased, and the number of untreated patients decreased.

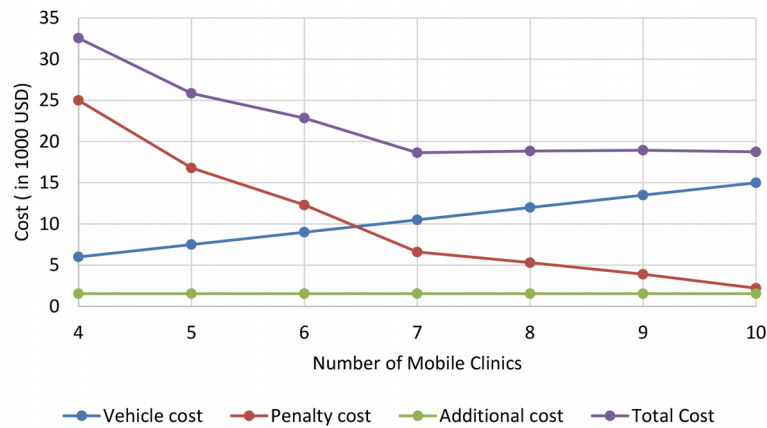


Figure 2. Relationship between the number of mobile clinics dispatched to vehicle cost, penalty cost due to unmet patients, and total cost

5.2. Model Analysis and Evaluation for Strategies

In this section, specific observations are made and the results are used to highlight the significance of the proposed mobile health clinic routing under the hybrid policy. The implications of having a medical care center in a shelter with more than 600 people were also investigated. The results showed that having several mobile clinics in the same locations is costly and inefficient. A medical shelter is often set up after mass evacuation, based on practical considerations. A location with a high number of displaced people and routing mobile clinics for several shelter locations with a small number of people was examined. The cost of setting up a medical shelter is equal to three units of MHC, approximately \$4,500. Table 3 presents the results of the analysis. According to the numerical results in the previous section, MHCs are beneficial when there are many shelters with a small number of displaced people. MHCs tend to serve many locations within walking distance and routing them to reach other areas within a stipulated time. In this case, the number of patients per location was small. Based on the numerical data used in this study, the locations were clustered, thereby allowing the mobile facility routing concept to be analyzed. However, assuming that the location of each shelter is dispersed without a cluster, this problem is closely related to vehicle routing. This strategy is not an appropriate option in a location with a large number of displaced people expected. With a large number of people in a shelter, there is a need to build more to render better services. When the location of all shelters is centered within walking distance, it is possible for healthcare personnel to cover several shelters. This leads to higher costs in the initialization process.

The results in Table 4 are optimal for the five selected scenarios because the effect also varies with the probability of occurrence changes. Several factors often cause disasters to impact the physical health of people living in affected areas and the disruption of medical infrastructure. Injury-related issues, contact with environmental contaminants, clinical conditions due to stress, lack of access to medical services, and continuous care disruptions affect the population's health status. When medical care is urgently needed, its capacity is often diminished, forcing external responders to render these services. MHCs have been implemented during disaster response in several

countries to help reach populations that lack access to medical care. Initially, the MHC service had several logistics problems to handle, such as optimizing the coverage and vehicle utilization.

	Total Cost	Expected Unmet Needs	Number of Medical Shelters	Location of Medical Shelter	Number of Mobile Clinics	Location Selected
Base Policy (MHCs)	17,335.5	66	0	-	7	1, 2, 5, 6, 7
Hybrid Policy (Medical Shelter and MHCs)	12,917.0	20	1	1	4	2, 5, 6, 7
Shelter Policy (Medical Shelter)	20,187.5	20	4	1, 3, 6, 7	0	-

Table 4. Result comparison of base policy and hybrid policy

6. Conclusion

As large-scale disasters are often unpredictable, limited on-site medical services have not met or addressed the needs of the sick and wounded. Many severely injured patients are transferred to available hospitals, whereas those with minor injuries receive medical treatment. Evacuated areas, inadequate sanitation, and improper treatment can worsen the health conditions of some people. To minimize accidental casualties and reduce the degree of disability, moving the health clinics' platform toward the disaster scene has been a focus in modern medical and trauma care philosophy.

The mobile health clinics were modeled into facility routing problems with a stochastic scenario and an objective to create MHCs to cover as many patients as possible within a prespecified time horizon. MHCs provide medical care to those who cannot access these facilities during the disaster response phase. The results also suggest how pre-disaster decisions regarding locations impact the affected population. Regarding the available locations for mobile clinics to be stationed, positioning them to serve several shelters resulted in cost minimization, thereby reducing the number of untreated people rather than routing.

A mobile health clinic needs to be operated in the nearest open area accessible by road, where the injured or medical care patient receives treatment. These MHCs play active roles in emergency rescue and serve as substitutes for local hospitals destroyed during disasters. Healthcare-related organizations and both government and non-governmental agencies that provide medical care services have to work together, including sharing a communication and information system to benefit the affected population. In this case, the resource-allocation problem is minimized. Although the mobile clinic's contributions to the entire disaster operation are not as significant, its additional availability reduces the burden on local health authorities. This reduces the suffering of the affected population.

Future research should address some important extensions of the model. First, future research should consider the maximum walking distance required to access MHCs during disasters. Second, a multiperiod case should be considered to understand the scheduling system when only limited mobile clinics are available. The multiperiod case might help understand the actual number of mobile clinics needed. Third, different services and their actual service times should be considered. Thus, the total number of patients served differs according to the type of service required.

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