



Multi-objective Model to Distribute Relief Items After the Disaster by Considering Location Priority, Airborne Vehicles, Ground Vehicles, and Emergency Roadway Repair

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Abstract. The most important aim in humanity's relief problems is the minimization of response time and reducing the rate of casualty in disasters. If paths are inappropriate for transferring relief items to the disaster areas, response time and the number of casualties will be increased. Therefore, airborne vehicles like helicopters are used in this study to transfer equipment to the disaster areas to build a "Field hospital." Each path is assigned a weight for illustrating priority and humanitarian operation starts its operation from the highest priority. What the instances' evaluations conclude is that most of the injured individuals are rescued by this strategy because the humanitarian operation is independent of paths' situation, and humanitarian operation time will be reduced. We wish to present the innovation of airborne and ground vehicles by reviewing demand priority in the disaster literature to show its efficiency in humanitarian operations. This study shows that the airborne vehicle strategy is cost-efficient and reduces the response time to extend possible; thus, the casualty rate could be decreased.

Keywords: Humanity relief · Airborne vehicles · Ground vehicles · Routing problem · Priority relief

1 Introduction

According to the occurrence of natural disasters, such as floods, earthquakes, and hurricanes worldwide, financial and casualty damages hurt human beings' lives. Referring to some criteria or factors, like population growth and climate changes, we can see an increase in natural disaster happenings. It is predicting that the present help is insufficient to respond to all the demands. The accidental and unpredictable nature of natural crises necessitates comprehensive plans to decrease the danger. In this regard, one of the most critical decisions is to have essential facilities distribution plans: relief team, tent, drug, ambulance.

The destruction of roads in a natural disaster occurrence entails traffic and disorder in transportation systems, also cease the relief operations, rescue teams, and the ambulance movements. So, road reliability is defined according to road damage percentage. Ability and high capability in distribution result in a quicker launching of roads for land vehicles to deliver required resources at the desired location on time. Hence, how to repair damaged roads in the least possible time is an important issue after a catastrophe.

On the one hand, the main concern of solving these issues is saving the lives of injured people and preventing more casualties, and on the other hand, much time is needed to reopen blocked land routes to cities and villages, so lots of injured people will lose their lives. Consequently, the best solution is to provide airborne assistance to different areas at a time when the landing path is reopening. Drugs, medical teams, and first aid depots can be delivered by helicopters, and after the reopening of the land route, food, and other necessities -like tents- will also be sent.

Based on the high limitations in relief supplies and equipment in the widespread catastrophic occurrence, we cannot respond to all affected cities and areas at the same time. So, authorities prioritize them based on criteria in the way to rescue the maximum population, who are likely to be injured and killed, in every relief operation. Accordingly, we have also taken our interest in maximizing the satisfaction of the community.

In this research, we attempt to choose the most effective strategy to minimize the number of people killed during the disaster, according to available facilities: air and ground vehicles, medical supplies, hygienic accessories, and heating for the disaster-stricken people. This paper reviews both airborne and ground vehicles in disaster literature and considers location's priority and repair groups. Due to the sensitivity of time, we suggest the strategy of delivery in the fastest possible way. For this reason, medical assistance is sent using helicopters to save the injured people, and then health accessories and food will be sent through ground vehicles. The importance of all paths is various, and in the following chapters, we will discuss the method for determining this factor.

2 Literature Review

In recent years, ambulance routing issues have tried to make the model work. The goals of research in this area are high convergence and coherence; for example, Chang et al. [1] examined the logistics' timing in crises and assumed resource diversion (nurses, transportation car for food, ambulances) for limited resource conditions. The goals achieved in this research are: 1) minimizing unsatisfied applications 2) minimizing the time to reach the region where the disaster has occurred 3) Minimizing the cost of logistics in the transportation sector.

From other articles in the field of transportation networks, research of [2] describes the effect of stored equipment, which will ultimately lead to a decrease in the number of deaths. This paper includes restrictions on the way, time, the number of expedition cars, the division of each area into sub-section, and it considers a rescue bus-including a doctor, five nurses, three dogs, and some food-that can save 15 people.

In the field of ambulance allocation for quick services, we can mention [3] that increased the performance of the model to a desirable level for various areas (urban and rural areas) by several ambulances. These assumptions helped to cover many natural disasters that affect different areas and provide proper relief. The article [4] presents the model by considering the blocking path and then opening the path by specific means. The research has a multi-objective problem, and its purposes are: 1) minimizing the time to arrive at the disaster area, 2) minimizing the total costs, and 3) maximizing the reliability level in serving the victims of the incident. Also, it solved the model using two meta-heuristic algorithms and provided acceptable numerical answers. According to reducing the number of deaths in disaster areas, we can use various technologies, including different relief vehicles. Helicopters are one of the most used vehicles in post-disaster situations. Due to the difficulties of ground transportation in case of a catastrophic event, the article [5] considered a medium-scale UAV helicopter for commodity transportation in the first few hours after the earthquake.

The prioritizing process for multiple patients when resources are insufficient for the rapid treatment of all patients is the topic of the study [6]. It develops an integrated criterion for mass casualty categorization to ensure interoperability and standardization to respond to an incident that has four categories: general considerations, global sorting, interventions life-saving, and individual assessment of patient classification. Further studies can be referred to the article [7] that prioritizes patients to get services. It divides the ambulance cost into two fixed and variable costs. The variable costs are proportional to the distance traveled by ambulance. In the research, two objective functions are considered, the first objective function is to minimize the response time, and the second is to minimize the total cost.

Another study was [8], in which a cost for an ambulance to move is considered, and it provides a model for balancing cost and responsibility. As expected, this study considers several objectives and seeks an ideal way to satisfy constraints and optimize answers. To this end, minimizing the total transportation costs and the sum of the earliness or tardiness of the transferring times is considered in the paper [9], and a multi-objective mathematical model and fuzzy parameters have been considered to make the modeling results more realistic.

Since the adequate response to public demands, through the first aid providing and transporting injured to the hospital's emergency department is a vital process, researchers are interested in modeling with the constraints of reality as closely as possible and using different methods to solve models. Therefore, [10] used existing models in their research and presented new results using uncertainty-based simulation. Whereas the article [11] modeled the problems related to cost, dynamic demand, and real-time service, using OR/MS models, and in this regard, uncertain data, the dynamic systems, and soft OR are used.

Patients' triage after entering the hospital ward is one of the issues in the field of health. This can be done in many different categories, including the severity of the illness or injury, prioritizing patients for treatment, and making the most of emergency department operations. In the article [12] the reliability and validity of the triage of patients in 3 and 5 categories are evaluated by nurses' experience in patient classification and evaluated in terms of managerial values. This study shows that the five triages category is safer and more highly reliable than the 3-category system. In the paper [13], the objective is to determine the efficiency of the simple classification and rapid treatment model, which was evaluated in a 2003 train crash disaster. It obtained the arrival time of the wounded people to the hospital and determined the correct patient triage values using a combination of modified Baxt criteria and hospital admission.

Systematic perspectives on technological disasters and incidents, especially human disasters [14] have been addressed. This study discusses the impact of two common barriers to learning from natural disasters: (1) information disruption; and (2) organizational policies, as well as ways to address these barriers.

One of the challenges faced at the regional and country-level is identified standards and criteria for measuring flexibility in events. The paper [15] provided a new framework, the disaster flexibility model, to improve the relative assessment of disaster resilience locally or socially.

Mathematical models, along with other optimization methods, have been used in many studies, including the article [16]. This paper presented two mathematical models and simulation methods for locating and enhancing the efficiency of ambulance services with the aims of 1) minimizing the maximum response time in emergency medical care, 2) minimizing the number of ambulances, and 3) optimizing the minimum costs involved. Initially, the problem constraints are defined by solving the problem of location regardless of the number of ambulances in each center and then allocating ambulances. In another paper with the linear mathematical model and simulation method presented by [17], the authors considered a complex nonlinear problem involving decision making with uncertain parameters and an iterative optimization algorithm. In this study [18] a multi-objective MINLP mathematical model with several uncertain parameters is developed. The authors in this article [19] focused on assessing the conditions and requirements after a disaster. A humanitarian relief supply chain is recently developed by [20] and they analyzed repair groups, reliability of routes, and monitoring operation before distributing relief items in various stages (Table 1).

Table 1. Related recent papers in humanitarian relief supply chain

reference	Features					objective			
	Relief items	Quick response	Reliability of route	Repair groups	Air-borne system	Reliability	Response time	Total cost	Air-borne completion time
This study	√	√	√	√	√	√	√	√	√
[1]	√	√	----	----	----	----	√	----	----
[2]	√	√	√	----	----	√	----	----	----
[3]	----	√	√	√	----	----	√	----	----
[4]	√	√	√	√	----	√	√	√	----
[5]	----	√	----	----	√	----	√	----	√
[6]	----	√	----	----	----	----	√	----	----
[7]	√	√	----	----	----	----	√	√	√
[8]	√	√	----	----	----	----	√	√	----
[9]	----	----	----	----	----	----	√	√	----
[10]	----	√	----	----	----	----	√	√	----
[11]	----	√	----	----	----	----	√	----	----
[12]	----	√	----	----	----	√	√	----	----
[13]	----	√	----	----	----	----	√	----	----
[14]	----	----	----	----	----	----	----	√	----
[15]	----	√	----	----	----	----	√	----	----
[16]	----	√	----	----	----	----	√	√	----
[17]	----	√	√	----	----	√	√	----	----

3 Problem Definition

In this research, we consider a relief network distribution like [4], comes with two types of relief operation: airborne and ground relief, specific plan and routing for increasing efficiency. Since not all disaster areas have the same degree of priority, we adopt a formula to determine the priority of the zones, inspired by the modeling of the problem in the article [2]. For this purpose, Formula I indicate the degree of priority:

$$l_{ij} = \frac{\text{population of a disaster district}}{\text{total population of disaster zone}}$$

In the first step, the information of disaster areas, which considers the number of injured people and their locations, is sent to relief centers. Relief centers allocate a priority number to each disaster area, and relief operations start with the biggest priority number and continue until the last disaster area. In this method, the disaster area with more

injured people or has the worst situation is served sooner than disaster areas with more appropriate situations. Because the roads are in an inappropriate situation for transferring vital items to disaster areas and time is so important in this case, helicopters are used to transfer vital items to disaster areas in the shortest time for “Field hospital”. The helicopters transport initial equipment medicals and medical teams to disaster areas; then medical teams start building field hospitals and treating injured people to save their lives. With this method, response time is decreased to the extent. Helicopters come back to distributions, pick up other medical team items, and transfer them to another disaster area. This process continues until all the disaster areas have field hospitals. So, we utilize helicopters to satisfy humanity’s main objective and decrease the dead people rate.

While helicopters transfer medical equipment and medical teams, repair groups start their duty to increase the reliability of each road and make a good situation for sharing relief items (for example, food, blanket, and tents) to disaster areas. Similar to the previous step, all relief operations start from the biggest priority number. This step boosts the speed of response time for relief items and helps people in disaster areas. Ground vehicles are sent to disaster areas in the last step, and they deliver relief items. The ground vehicles do not come back to distributions and stay at disaster areas. Each disaster area can receive relief items from different ground vehicles.

3.1 Assumptions

1. Information is collected completely and sent to distributions.
2. Each disaster area could be visited several times.
3. Ground vehicles do not come back to distributions.
4. Field hospitals locate next to disaster areas.
5. Both vehicles are capacitated.
6. Airborne vehicles can transfer appropriate equipment, nurses, and doctors to establish field hospitals.
7. The shortage is not considered.
8. Distributions are not allowed to send vehicles to each other.
9. An appropriate situation is considered, so sufficient vehicles, equipment, nurses, and doctors are available.
10. Loading and discharging time of ground vehicles are not considered since repairing roads needs time and at this time the ground vehicles prepare themselves for fast operation.

Now notations are introduced:

Sets

- N Set of disaster areas $\{1; \dots; n\}$
 M Set of candidate distribution nodes or centres $\{n + 1, \dots, n + m\}$
 V Set of nodes $\{1; \dots; n + m\}$
 K Set of vehicles $\{1; \dots; k\}$
 T Set of time periods $\{1; \dots; t\}$
 L Set of relief $\{1; \dots; l\}$

- E Set of available traffic links $\{(i,j), i,j \in V, i \neq j\}$
 i, j Indices to nodes $i, j \in V$
 l Indices to relief
 k Indices to aerial vehicles
 t Indices to time periods
 G Set of repair groups
 H Set of helicopters
 O Set of candidate hospitals

Parameters

- f_j Fixed cost of constructing the distribution nodes $j, \forall j \in M$
 W Cost of each repairing work teams in each period
 d_{ij} Distance of link $(i,j), \forall (i,j) \in E$
 h_{ij} Road damage percentage between nodes i and $j, i, j \in V$
 e_{ij} Number of time periods needed for repairing road between nodes i and $j, (i,j) \in E$
 D_{ilj} Quantity of relief l demanded by disaster area i , at any period
 uv_l Unit volume of relief $l, \forall l \in L$
 c_k Transportation cost per kilometer of vehicle $k, \forall k \in K$
 Q_l Amount of relief l available in a traffic network, $\forall l \in L$
 v_k The normal speed of vehicle $k, \forall k \in K$
 l_k Loading capacity of aerial vehicle $k, \forall k \in K$
 G Number of available work teams
 I_j Weight of node
 B_j Duration of discharge from a helicopter
 B_i Duration of loading
 N_h Number of helicopters

Decision variables

- x_{jt} Equal = 1 if candidate DC j is opened at period t , 0, else, $\forall i \in j, t \in T$
 y_{ijkt} Equal = 1 if i precedes j in route of aerial vehicle k at period t , 0, else
 y'_{ijht} Equal = 1 if helicopter h does its mission at ij in period t , 0, else
 z_{ijkt} Equal = 1 if i is on the route of aerial vehicle k in period t , 0, else, $\forall k \in K, t \in T, (i,j) \in E$
 vf_{ikt} Equal = 1 if the last demand point serviced by aerial vehicle k is a node $i \in N$; 0, else
 p_{ijt} Equal = 1 if a work team starts repairing road between nodes i and j at period t
 r_{ijt} Reliability of road between nodes i and j in period t
 dev_{ilt} Amount of unsatisfied demand relief type l at node
 I At the end of the operation at period t
 q_{ilk} Quantity of relief l distributed by K to demand point i at period $t, \forall k \in K, l \in L, i \in V$
 c_{ij}^g Repair completion of g th group
 C_{ij}^h Completion of helicopter mission
 s_{ij}^g Start time of repair

s_{ij}^h Start time of helicopter mission
 x_{ijji} If repair of ij before ji

Model

$$f_1 = \text{Min}(\text{Max} \left\{ \sum_{(i,j) \in E} \sum_k \sum_t I_j \cdot \left(\frac{d_{ij} \cdot y_{ijkt}}{v_k} \right) \right\}) \tag{1}$$

$$f_2 = \min \sum_{j \in M} \sum_{t \in T} f_j \cdot x_{jt} + \sum_{k \in K} \sum_{(i,j) \in E} \sum_{t \in T} c_k \cdot d_{ij} \cdot y_{ijkt} + \sum_{(i,j) \in E} \sum_{t \in T} w \cdot e_{ij} \cdot p_{ijt} \tag{2}$$

$$f_3 = \max \sum_{(i,j) \in E} \sum_{t \in T} \sum_{k \in K} r_{ij} \cdot y_{ijkt} \tag{3}$$

$$f_4 = \min \sum_{(i,j) \in E} c_{ij}^h \cdot I_j \tag{4}$$

Subject to:

$$x_{it} \geq y_{ijkt} \quad \forall i \in M, (i, j) \in E, k \in K, t \in T : i \neq j \tag{5}$$

$$x_{it} \geq z_{ikt} \quad \forall i \in M, (i, j) \in E, k \in K, t \in T \tag{6}$$

$$z_{ikt} \geq y_{ijkt} \quad \forall i \in V, (i, j) \in E, k \in K, t \in T : i \neq j \tag{7}$$

$$z_{ikt} \geq VF_{ikt} \quad \forall i \in V, k \in K, t \in T \tag{8}$$

$$\sum_{k \in K} VF_{ikt} = 1, \forall k \in K, t \in T \tag{9}$$

$$\sum_{k \in K} y_{ijkt} \leq 1, \forall (i, j) \in E, t \in T : i \neq j \tag{10}$$

$$\sum_{j \in V} y_{ijkt} \leq 1, \forall i \in N, k \in K, t \in T : i \neq j \tag{11}$$

$$\sum_{i \in M} \sum_{j \in N} y_{ijkt} \leq 1, \forall k \in K, t \in T \tag{12}$$

$$\sum_{i \in M} \sum_{j \in N} \sum_{k \in K} q_{jilk} \cdot z_{ikt} \leq Q_l, \forall l \in L, t \in T \tag{13}$$

$$deV_{jlt} = D_{jlt} - \left(\sum_{k \in K} q_{jilk} \right) \geq 0, \forall j \in N, l \in L, t \in T \tag{14}$$

$$\sum_{j \in N} \sum_{l \in L} uv_l \cdot q_{jilk} \leq L_k, \forall k \in K, t \in T \tag{15}$$

$$\sum_{j/(j,i) \in E} y_{jikt} - \sum_{j/(j,i) \in E} y_{ijkt} = \begin{cases} 1 & VF_{ikt} = 1, i \in N, t \in T : i \neq j \\ -1 & z_{ikt} = 1, i \in M, \forall k \in K, t \in T : i \neq j \\ 0 & \text{else} \end{cases} \quad (16)$$

$$\sum_{i \in V} \sum_{k \in K} y_{ijkt} \geq 1, \forall j \in N, t \in T \quad (17)$$

$$r_{ijt} = 1 - h_{ij} \left(1 - \sum_{t'=1}^{t-e_{ij}} p_{ijt'} \right), \forall i, j \in V, t \in T \quad (18)$$

$$y_{ijkt} \leq 1 - \sum_{t'=t+e_{ij}+1}^t p_{ijt'}, \forall t \in T, k \in K, i, j \in V \quad (19)$$

$$\sum_{i \in V} \sum_{j \in V} p_{ijt} \leq G, \forall t \in T, i \neq j \quad (20)$$

$$\sum_{i \in M} y_{ijkt} = 0, \forall j \in M, k \in K, t \in T \quad (21)$$

$$u_{ikt} - u_{jkt} + n \cdot y_{ijkt} \leq n - 1, \forall i, j \in N, k \in K, t \in T : i \neq j \quad (22)$$

$$x_{it} \geq y'_{ij'ht} \quad \forall i \in M, j' \in O, h \in H, t \in T \quad (23)$$

$$\sum_{h \in H} y'_{ij'ht} \leq 1 \quad \forall i \in M, j' \in O, t \in T \quad (24)$$

$$\sum_{i \in V} y'_{ij'ht} \leq 1 \quad \forall j' \in O, h \in H, t \in T \quad (25)$$

$$\sum_{i \in M} \sum_{j' \in O} y'_{ij'ht} \leq 1 \quad \forall h \in H, t \in T \quad (26)$$

$$\sum_{i \in V} \sum_{j' \in O} \sum_{h \in H} y'_{ij'ht} \leq N_h \quad \forall j' \in O, h \in H, t \in T \quad (27)$$

$$\sum_{i \in V} \sum_{j' \in O} \sum_{t \in T} y'_{ij'ht} = 1 \quad \forall j' \in O, h \in H, t \in T \quad (28)$$

$$\sum_{i \in M} y'_{ij'ht} = 0 \quad \forall j' \in O, h \in H, t \in T \quad (29)$$

$$\sum_{i \in M} \sum_{j' \in O} \sum_{h \in H} y'_{ij'ht} \leq G_h \quad \forall t \in T \quad (30)$$

$$c_{ij'}^h = \left(\frac{d_{ij}}{v_h} + B'_i + B_j\right) \cdot y'_{ij'ht} \tag{31}$$

$$q_{ilkt} \geq 0, \forall (i, j) \in E, l \in L, k \in K, t \in T \tag{32}$$

$$s_{ij}^g, s_{ij}^h, c_{ij}^h \geq 0, ; i \in M, j \in N, g \in G, h \in H \tag{33}$$

$$x_{it} \in (0, 1), \forall i \in M, t \in T \tag{34}$$

$$y_{ijkt} \in (0, 1), \forall (i, j) \in E, k \in K, t \in T \tag{35}$$

$$z_{ikt} \in (0, 1), \forall i \in V, k \in K, t \in T \tag{36}$$

$$VF_{ikt} \in (0, 1), \forall i \in N, k \in K, t \in T \tag{37}$$

$$u_{ikt} \in (0, 1), \forall i \in N, k \in K, t \in T \tag{38}$$

$$x_{ij'j'} \in (0, 1), \forall i, i' \in M, j, j' \in N, i \neq i', j \neq j' \tag{39}$$

$$y'_{ij'ht}, u_{j'ht}, x'_{j't} \in (0, 1) \tag{40}$$

In the first objective function, we minimize the maximum time of vehicle passing by choosing the disaster zone based on the defined priority. The maximum transit time means the lowest time to complete the service among all the disaster nodes. In the second objective function, total costs are minimized. The model simultaneously provides the number and location of distribution centers, the allocation of disaster zones to distribution centers and vehicle routes so that the total cost includes three components: (1) fixed cost of establishing distribution centers; (2) transportation costs of vehicles; (3) Cost of repairing damaged roads. In objective function three, the minimum route reliability is maximized: In an earthquake, many infrastructures (roads, bridges, tunnels) are damaged, and these damages may increase in aftershocks. In this study, to prevent secondary injuries, we determine the reliability of the route as the probability of saving workers to accelerate across demand points. In the fourth objective function, the goal is to minimize the time required to complete the routes in air relief, where $j' \in O$ and O are the set of candidates for field hospital construction also, j' must be very close to j . It should be noted that the completion time of ground and airborne vehicles are considered in two separate objective functions (1 and 4). This is because the innovation in consideration of air vehicles can be more easily compared with the time of ground vehicles.

Equations (5) and (6) state that distribution centers can only obtain services. Equation (7) guarantees that any vehicle in any given period can travel through the connection (i, j) if and only if node i is in the path of each vehicle. Equation (8) specifies that the nodes at the end of the path of each vehicle in each period must deal with one vehicle. Equation (9) guarantees that each vehicle in each period must eventually be placed in

the disaster area or distribution center. Equation (10) shows that in each period, only one vehicle is selected for each route. Equation (11) guarantees that each vehicle operates once in most cases for each critical area in each period. Equation (12) ensures that each vehicle is shipped at most from one distribution center at any period. Equation (13) ensures that the amount of relief delivered from all distribution centers to critical areas cannot exceed the amount of relevant relief available. Equation (14) shows that the amount of relief distributed for each node in each period does not exceed the required value of this node. Equation (15) is shown in each period, the total amount of relief delivered at critical points by any vehicle not exceeding its capacity. Equation (16) expresses the consecutive motion and guarantees the assumption of path opening (Please see Appendix A). Equation (17) ensures that each disaster area can be visited at least once in each period. The split delivery hypothesis in this constraint has well demonstrated that the reliability of each road should be reliable (e.g., it will be equal to 1) considering the percentage of damage in each period calculated and after road reconstruction. Hence, Formula (18) calculates the reliability of roads in each period based on the relevant assumptions. Equation (19) shows that the destroyed or damaged road should not be used to deliver relief during reconstruction. Equation (20) limits the number of destroyed roads that can be rebuilt in each period based on the number of existing work teams. Equation (21) ensures that distribution centers are not correlated, meaning that goods are not exchanged between centers. Equation (22) is the constraint for the elimination sub-tours. Constraint (23) states that if the distribution center is built in a place, the transmission will take place from there. Restriction (24) ensures that up to one helicopter is assigned to each route. Constraint (25) guarantees that each route goes at most once. Equation (26) implies that a region receives one time from an air rescue distributor. Equation (27) ensures that the helicopters' missions to build a hospital will not exceed the number of helicopters. Equations (28, 29) indicate that each helicopter is assigned to one route and cannot visit other distributions. Formula (30) guarantees the capacity limitation of the number of helicopters available in air support. Formula (31) provides the completion time of the air relief process. From constraints (32) to (40) apply to nonnegative, integer, zero, and one values for decision variables.

4 Solution Methods

In the rest of the research, we consider two different problems, then we will solve them and evaluate the results.

These problems are solved by GAMS (LP-metrics technique), and obviously, all objectives cannot be satisfied simultaneously because this is a multi-objective problem. This technique minimizes the gaps which appear between optimal results and multi-objective results [21]. Moreover, it should be noticed ANTIGONE solver is selected to solve our problems.

$$L_p = \left[\sum_{k=1}^k (\pi_k W_k - b_k)^p \right]^{\frac{1}{p}} \quad \text{II}$$

In Formula II, p determines which family of LP-metric is used, and the weights of objectives are determined by π_k [22].

5 Numerical Example

5.1 Computational Experiments

The GAMS approach is an exact approach that is used for small and medium-scale problems. ANTIGONE solver is used for solving three problems. These problems' data are determined below (Table 2).

The first problem's data is presented below:

Table 2. Initial information of the first problem

Sets	
Set of potential distributions	A, B
Set of demand points	1, 2, 3
Set of ground vehicles	K1, k2
Set of relief items	Med, Food
Set of helicopters	h1, h2, h3

This example assumes two distributions and three disaster areas. Fix costs of establishing distributions are considered $A = 40$, $B = 30$. The relief items' volumes are Medicine = 2, Food = 1. Transportation costs for ground vehicles are $k1 = 5$, $K2 = 7$ and the normal speed of them are $Vk1 = 50$, $Vk2 = 60$. Its vehicles' capacities are $k1 = 300$ and $K2 = 400$. The helicopters' speeds are considered $Vh1 = 30$, $Vh2 = 35$, $Vh3 = 20$, moreover, both loading and discharging times for helicopters are considered 2. Weight of demand points are $1 = 0.2$, $2 = 0.3$ and $3 = 0.5$ (Tables 3, 4 and 5).

Table 3. Distance between distributions and demand points of the first problem

	1	2	3
A	100	100	80
B	150	120	110

Table 4. Road damage of the first problem

	1	2	3
A	0.2	0.1	0.4
B	0.3	0.4	0.3

Table 5. Repair time of route for the first problem

	1	2	3
A	1	2	1
B	2	1	1

The following tables show the data used to solve the model in the second instance (Tables 6 and 7):

Table 6. The demand for relief items for the first problem

	1	2	3
Medicine	5	7	8
Food	6	5	5

Table 7. Initial information of the second problem

Sets	
Set of potential distributions	A, B, C
Set of demand points	1, 2, 3, 4, 5, 6
Set of ground vehicles	k1, k2
Set of relief items	Med, Food
Set of helicopters	h1, h2, h3, h4, h5, h6

In the second instance, we considered three distribution centers and six demand areas. The fixed cost of establishing distributions is considered $A = 40$, $B = 30$, $C = 36$. The relief items' volumes are Medicine = 2, Food = 1. Transportation costs for ground vehicles are $K1 = 5$, $K2 = 5$ and the normal speed of them are $Vk1 = 50$, $Vk2 = 60$. Its vehicles' capacity of the first and second vehicles are 300 and 400, respectively. The helicopters' speeds are considered $Vh1 = 30$, $Vh2 = 35$, $Vh3 = 20$, $Vh4 = 30$, $Vh5 = 20$ and $Vh6 = 30$. Moreover, both loading and discharging time for helicopters are considered 2. Weight of demand points are $1 = 0.2$, $2 = 0.3$, $3 = 0.5$, $4 = 0.4$, $5 = 0.5$ and $6 = 0.7$ (Tables 8, 9, 10, and 11).

Table 8. Distance between distributions and demand points of the second problem

	1	2	3	4	5	6
A	100	100	80	100	180	80
B	150	120	110	120	200	60
C	100	90	200	139	130	100

Table 9. Road damage of the second problem

	1	2	3	4	5	6
A	0.2	0.1	0.4	0.3	0.2	0.4
B	0.3	0.4	0.3	0.4	0.1	0.4
C	0.5	0.7	0.4	0.1	0.7	0.4

Table 10. Repair time of route for the second problem

	1	2	3	4	5	6
A	1	2	1	2	1	2
B	2	1	1	2	3	2
C	2	3	1	1	3	2

Table 11. The demand for relief items for the second problem

	1	2	3	4	5	6
Medicine	5	7	8	3	7	7
Food	6	5	5	6	5	4

5.2 Model Validation

In this section, we verify the quality of the model and evaluate some analyses. Finally, we approve the validation of the model.

If all loading times are multiplied twice at the first problem, the completion time of the helicopter will be changed (old result + (number of helicopters*2)). As Fig. 1 illustrates in the first problem, number 2 means that each loading time is doubled, and number 4 shows that every loading bar is multiples four times and so on.

Figure 2 shows the repair cost that is added to several units (old number + 3*number of the route). As the given bar chart presents in the first problem, number 3 shows repair cost is added three units and so on.

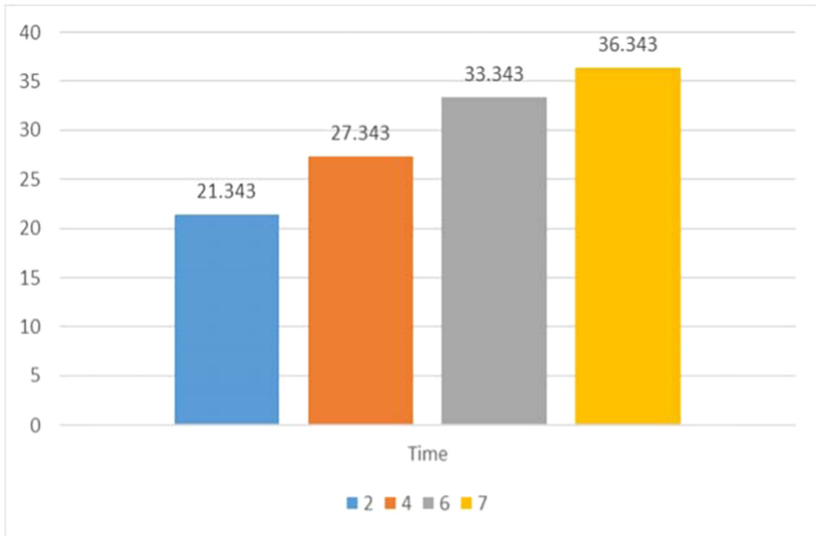


Fig. 1. Loading time validation

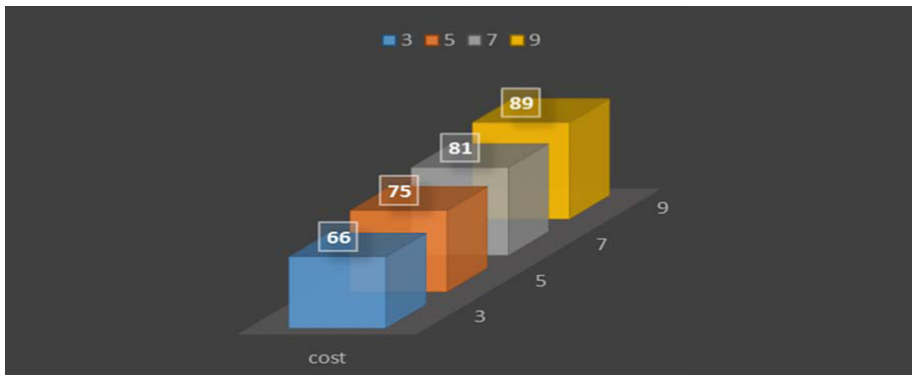


Fig. 2. Repair cost validation

6 Result and Discussion

6.1 Results

All initial parameters are determined and used in the GAMS. Different objective weights obtain various answers, but all objectives cannot satisfy, simultaneously.

All the first problem results are shown in Table 12:

Table 12. Small scale’s results

Test problem number	Weight of objective function				Objective function value			
	w1	w2	w3	w4	f1	f2	f3	f4
1	0.25	0.25	0.25	0.25	12.42	25087	5.2	8.25
2	0.6	0.2	0.1	0.1	11.65	23365	5	9.04
3	0.2	0.6	0.1	0.1	12.6	17365	5	9.04
4	0.2	0.1	0.6	0.1	12.6	26550	5.6	9.04
5	0.2	0.1	0.1	0.6	12.6	26550	5	7.34

According to Table 12, each test problem has a different priority, and selecting each of them depends on the situation. In test problem number 1, all objectives have equal weight, so priority is not considered. The first and second objectives have some challenges to each other. As a result, neither of them is satisfied. The first objective selects vehicles with the highest speed while they are expensive, so the second objective chooses other vehicles. In other test problems, the results have changed.

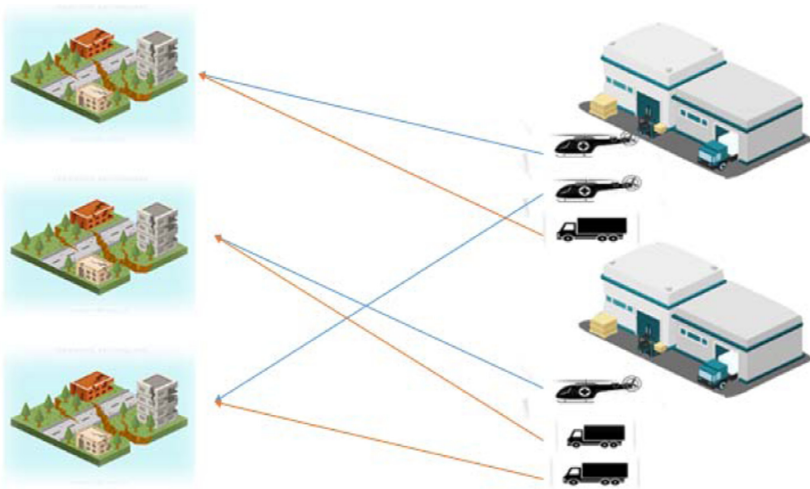


Fig. 3. Relief items operation

The given Fig. 3 shows how helicopters and trucks are allocated to demand points. Distribution A sends helicopter 3 to disaster area number 1 and helicopter 2 to disaster area number 3. Also, distribution B sends helicopter 1 to disaster area number 2. Ground vehicles are allocated like helicopters. Distribution A covers one area and distribution B covers two areas. GAMS determine this allocation.

All the second problem results are shown in Table 13:

Table 13. Medium scale’s results

Test problem number	Weight of objective function				Objective function value			
	w1	w2	w3	w4	f1	f2	f3	f4
1	0.25	0.25	0.25	0.25	28.996	16981	15.7	12.04
2	0.6	0.2	0.1	0.1	27.196	17028	14.1	18.94
3	0.2	0.6	0.1	0.1	29.112	14821	14.1	18.94
4	0.2	0.1	0.6	0.1	29.112	19821	16.8	18.94
5	0.2	0.1	0.1	0.6	29.112	19821	14.1	9.87

As Table 13 illustrates, different test problems are evaluated. It depends on the situation in which managers select the results. Like the previous problem, all objectives are not satisfied. Test problem 1 considers all objective functions have equal priority and solves the model.

6.2 Sensitive Analysis

Now in this section key parameters are evaluated, but at the first, the research wants to show how much its innovation has an effective impact on the response time. As mentioned above, the chief objective of this research is minimizing the response time. As Fig. 4 shows, airborne vehicles have an efficient effect on response time. Obviously, if helicopters are not used for humanitarian operations, vital equipment will be delivered to demand points at an inappropriate time.

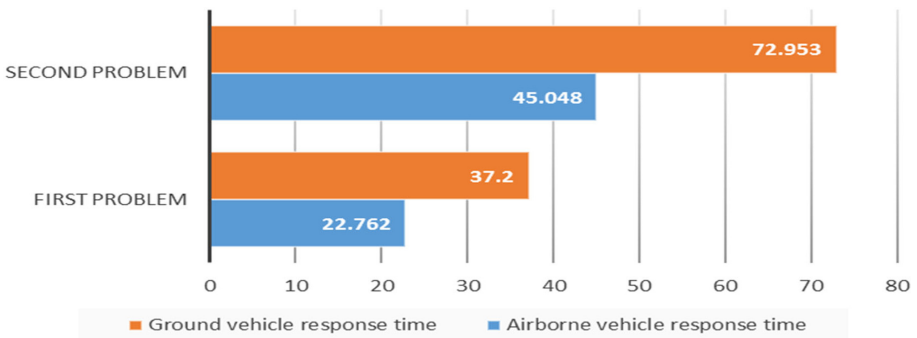


Fig. 4. Comparing airborne and ground vehicles

Figure 4 indicates that without helicopters at the first problem, this operation needs 37.2 h, and by considering helicopters, it needs 22.762 h. This time is reduced to about 15 h by airborne vehicles, also at the second problem, this reducing time is about 28 h. This completion time does not consider the demand points’ weight. Thus, all the above results prove that its innovation has an efficient effect on humanitarian operations.

Three important parameters that have a deep effect on response time are loading time, discharge time, and helicopters' speed. If the summation of these parameters is more than the ground vehicles' time, airborne vehicles will not be used. The given chart in Fig. 5 shows the comparison between objective number 4 and number 1.

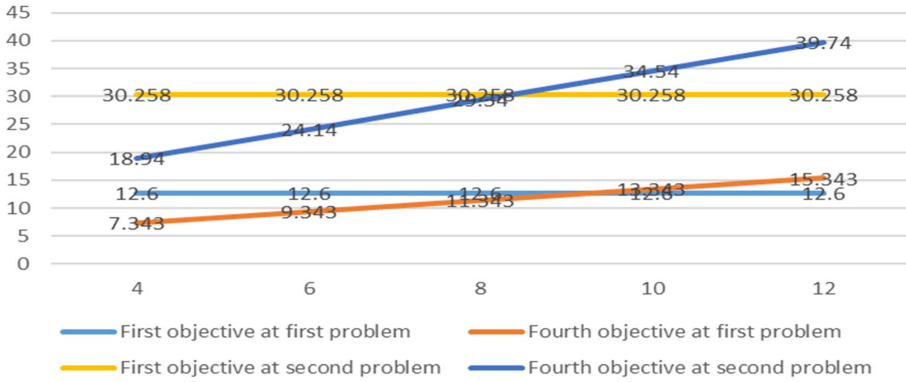


Fig. 5. Comparing first and fourth objective

In Fig. 5, the horizontal axle shows the sum of loading and discharge time for airborne vehicles. If total loading and discharge time have increased, ground vehicles will reach demand points sooner than airborne vehicles and it is not efficient because medicines have higher priority than the other relief items. Also, the chief objective of using helicopters is to minimize the response time and build a field hospital at an appropriate time. Therefore, using helicopters in this situation is not intellectual and economical due to helicopters are far more expensive than the trucks. Moreover, they reach demand points after trucks.

Now the road repair time is evaluated. As Fig. 6 presents, repair time has a deep effect on ground vehicles' response time, so if the repair times are more than a specific

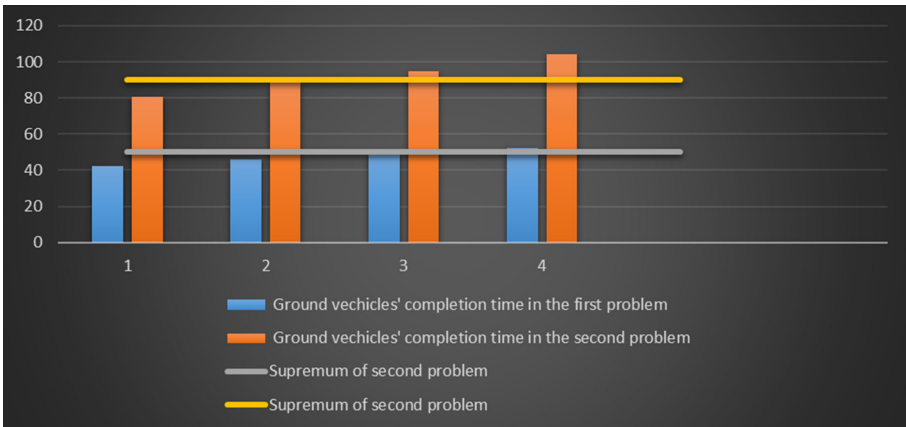


Fig. 6. Supremum of ground vehicles 'completion time

amount of time, the ground vehicles will not be used for operation since they cannot transfer relief items at the appropriate time. Figure 1 shows that every repair time is added by one and so on.

The manager of relief items operation can determine the specific number for ground vehicles' completion time. When their completion times exceed their supremum, the manager can use just airborne vehicles to the minimum completion time.

6.3 Discussion

We evaluate all results in two problems, and in this section, some challenges are examined. In the previous section, results prove that in some cases airborne vehicles are more efficient than ground vehicles and, in some cases, ground vehicles are more efficient, while in most cases cooperate both vehicles have the appropriate effect on humanitarian relief items operation. This approach can reduce the casualty and increase the response time to extend possible. But sometimes, airborne approaches are not used because of inappropriate weather; it is clear that helicopters cannot start their mission if weather is unsuitable for airborne operation. Moreover, it is so dangerous. So, the manager should focus on ground vehicles and repair groups to send relief items and medicine.

In some cases, the geographical location of disaster areas or demanding points is mountainous or hilly, so it is difficult to transfer relief items to demand points by ground vehicles or establishing field hospitals. In this case, the manager should decide on operations. Airborne vehicles are efficient in these areas and can transfer the injured people to appropriate situations and after the nurses and doctors start to cure them.

Ground and airborne vehicles are utilized to minimize the response time to extend possible. Although in some cases one of them is more efficient, the cooperation of them can help the humanitarian operation effectively, also manager role should not be ignored.

7 Conclusion

This research illustrates one humanitarian relief item operation which considers repair groups, different relief items, airborne and ground vehicles. It has four objectives for reducing response time and cost and increasing the reliability of the route. Reliability is one of the important evaluation criteria that is utilized for assessing different products [23]. Therefore, it is used to assess the route in this paper. Two problems (small and medium) are considered and solve by GAMS, and their results are presented in previous sections. The chief objective of this model is reducing response time to decrease casualties, and this aim is satisfied by considering airborne vehicles. They are used to transfer initial field hospitals' equipment and ample doctors and nurses; meanwhile, ground vehicles and repair groups transfer relief items. The models' results prove that helicopters have a special effect on the results and minimize response time very efficiently. Some challenges are available for this model, and managers should decide between them to choose the best approach for each of them.

Different weights are assigned to demand points by operation's information, and the operation starts to satisfy the demand point which has the highest weight or priority. This approach needs to correct information to determine their weight appropriately.

Further research for this study can be done in different sections. The limited budget for establishing distributions or using airborne or ground vehicles can be added. Limited ground or airborne vehicles will be an appropriate innovation that shows the importance of demand points better.

Appendix A

In this section, the linear model of Eq. 16 is presented. To solve the model by the GAMS (ANTIGONE solver), the linear model should be used.

$$\sum_{j/(j,i) \in E} y_{jikt} - \sum_{j/(j,i) \in E} y_{ijkt} \leq VF_{ikt} \cdot M, \quad i \in N, t \in T : i \neq j$$

$$\sum_{j/(j,i) \in E} y_{jikt} - \sum_{j/(j,i) \in E} y_{ijkt} \geq -z_{ikt} \cdot M, \quad i \in M, \forall k \in K, t \in T : i \neq j$$

Two above equations are presented in Eq. 16 in the model.

References

1. Chang, F.-S., et al.: Greedy-search-based multi-objective genetic algorithm for emergency logistics scheduling. *Expert Syst. Appl.* **41**(6), 2947–2956 (2014)
2. Edrissi, A., Nourinejad, M., Roorda, M.J.: Transportation network reliability in emergency response. *Transp. Res. Part E: Logist. Transp. Rev.* **80**, 56–73 (2015)
3. Leknes, H., et al.: Strategic ambulance location for heterogeneous regions. *Eur. J. Oper. Res.* **260**(1), 122–133 (2017)
4. Vahdani, B., Veysmoradi, D., Shekari, N., Mousavi, S.M.: Multi-objective, multi-period location-routing model to distribute relief after earthquake by considering emergency roadway repair. *Neural Comput. Appl.* **30**(3), 835–854 (2016). <https://doi.org/10.1007/s00521-016-2696-7>
5. Nedjati, A., Vizvari, B., Izbirak, G.: Post-earthquake response by small UAV helicopters. *Nat. Hazards* **80**(3), 1669–1688 (2015). <https://doi.org/10.1007/s11069-015-2046-6>
6. Lerner, E.B., et al.: Mass casualty triage: an evaluation of the science and refinement of a national guideline. *Disaster Med. Public Health Prep.* **5**(2), 129–137 (2011)
7. Rezaei-Malek, M., et al.: An approximation approach to a trade-off among efficiency, efficacy, and balance for relief pre-positioning in disaster management. *Transp. Res. Part E Logist. Transp. Rev.* **93**, 485–509 (2016)
8. Rezaei-Malek, M., Tavakkoli-Moghaddam, R.: Robust humanitarian relief logistics network planning. *Uncertain Supply Chain Manag.* **2**(2), 73–96 (2014)
9. Ghodrathnama, A., Tavakkoli-Moghaddam, R., Azaron, A.: Robust and fuzzy goal programming optimization approaches for a novel multi-objective hub location-allocation problem: a supply chain overview. *Appl. Soft Comput.* **37**, 255–276 (2015)
10. Jemai, Z., Aboueljainane, L., Sahin, E.: Emergency ambulance deployment in Val-De-Marne department a simulation-based iterative approach. In: *Proceedings of the 3rd International Conference on Simulation and Modeling Methodologies, Technologies and Applications*, vol. 1, pp. 565–576 (2013)
11. Altay, N. and Green III, W.G.: OR/MS research in disaster operations management. *Eur. J. Oper. Res.* **175**(1), 475–493 (2006).

12. Travers, D.A., et al.: Five-level triage system more effective than three-level in tertiary emergency department. *J. Emerg. Nurs.* **28**(5), 395–400 (2002)
13. Kahn, C.A., et al.: Does START triage work? An outcomes assessment after a disaster. *Ann. Emerg. Med.* **54**(3), 424–430. e1 (2009)
14. Pidgeon, N., O’Leary, M.: Man-made disasters: why technology and organizations (sometimes) fail. *Saf. Sci.* **34**(1–3), 15–30 (2000)
15. Cutter, S.L., et al.: A place-based model for understanding community resilience to natural disasters. *Glob. Environ. Chang.* **18**(4), 598–606 (2008)
16. Berlin, G.N., Liebman, J.C.: Mathematical analysis of emergency ambulance location. *Socioecon. Plann. Sci.* **8**(6), 323–328 (1974)
17. Kim, S.H., Lee, Y.H.: Iterative optimization algorithm with parameter estimation for the ambulance location problem. *Health Care Manag. Sci.* **19**(4), 362–382 (2015). <https://doi.org/10.1007/s10729-015-9332-4>
18. Abazari, S.R., Aghsami, A., Rabbani, M.: Prepositioning and distributing relief items in humanitarian logistics with uncertain parameters. *Socio-Econ. Plan. Sci.* **74**, 100933 (2021)
19. Danesh Alagheh Band, T.S., Aghsami, A., Rabbani, M.: A post-disaster assessment routing multi-objective problem under uncertain parameters. *Int. J. Eng.* **33**(12), 2503–2508 (2020)
20. Momeni, B., Aghsami, A., Rabbani, M.: Designing humanitarian relief supply chains by considering the reliability of route, repair groups and monitoring route. *Adv. Ind. Eng.* **53**(4), 93–126 (2019)
21. Rabbani, M., Aghsami, A., Farahmand, S., Keyhanian, S.: Risk and revenue of a lessor’s dynamic joint pricing and inventory planning with adjustment costs under differential inflation. *Int. J. Procur. Manag.* **11**(1), 1–35 (2018)
22. Ringuest, J.L.: Lp-metric sensitivity analysis for single and multi-attribute decision analysis. *Eur. J. Oper. Res.* **98**(3), 563–570 (1997)
23. Azadeh, A., Sheikhalishahi, M., Aghsami, A.: An integrated FTA-DFMEA approach for reliability analysis and product configuration considering warranty cost. *Prod. Eng. Res. Devel.* **9**(5–6), 635–646 (2015). <https://doi.org/10.1007/s11740-015-0642-7>