Advances in Industrial Engineering, Autumn 2019, 53(4): 93-126
DOI: 10.22059/jieng.2021.306436.1733

RESEARCH PAPER

Designing Humanitarian Relief Supply Chains by Considering the Reliability of Route, Repair Groups and Monitoring Route

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Received: 17 July 2020, Revised: 17 January 2021, Accepted: 21 January 2021

Abstract

Most humanitarian relief items' investigations try to satisfy demands in disaster areas in an appropriate time and reduce the rate of causality. Time is an essential element in humanitarian relief items; the quietest response time, the more rescued people. Reducing response time with high reliability is the main objective of this research. In our investigation, monitoring the route's situation after occurrence disaster with drones and motorcycles is planned for collecting information about routes and demand points in the first stage. The collected information is analyzed by the disaster management to determine the probability of each scenario. By evaluating collected data, the route repair groups are sent to increase the route's reliability. In the final step, the relief items operation allocates the relief items to demand points. All in all, this research tries to present a practical model and real situation to survive more people after the occurrence of the disaster. An exact solver solves the evolutionary model in small and medium scales; the developed model in big scale is solved by Grasshopper Optimization Algorithm (GOA), and then results are evaluated. The evaluation results indicate the positive effect of valid initial information on the humanitarian supply chain's performance.

Keywords:
Humanitarian Relief Supply Chain;
Monitoring Routes;
Repairing Groups;
Reliability of Routes;
Grasshopper Optimization Algorithm

Introduction

Unfortunately, Disasters happen all over the world and cause many destructive problems, which damage people in many aspects. People all over the world are grappling with these problems, and they are affected. After disasters, people may lose their properties without any support and they do not have ample purchasing power to replace the gone properties. All problems could heighten multiple if one member of the family is gone in disaster. The government wants to reduce the rate of dead people in disaster by using appropriate equipment and effective methods. Now the value of researchers, who study and design the humanitarian relief supply chain, is seen and the disaster management can use their results. Transferring relief items in the shortest time is the chief objective of most humanitarian relief supply chains. Therefore, the appropriate approach for satisfying demands at demand points should be adopted. All humanitarian relief supply chains do their best to increase the rate of satisfied demands at the appropriate time.

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Noham and Tzur [1] designed a two-echelon relief supply chain and presented a model for delivering a single relief item to disaster areas and consisted of some warehouses and distributions for this objective. But [1] did not determine how the initial information was obtained. Monitoring routes in the disaster was the main goal of Oruc and Kara [2], it paid special attention to monitor and check the reliability of the routes and did not consider delivering relief items to disaster areas. Drones and motorcycles did monitor due to they can collect information very soon to the extent possible. Vahdani et al. [3] was another research in disaster and considered some repair groups to repair the roads and increasing the reliability of roads and did not permit to move vehicles until the reliability of roads becomes one. Like Noham and Tzur [1], this research did not determine how information was obtained and assumes that initial information is given. According to the mentioned studies, we can conclude that although past studies have been able to provide efficient models, some processes have been ignored in their researches. Some questions are prompted for considering an efficient model: 1) How the initial information is obtained from the disaster points?, 2) How does the repair groups 'procedure allocate the repair groups to the blocked route?, and 3) How does the relief items operation work?

To answer these questions, we consider a humanitarian supply chain consists of warehouses, distribution candidates, and disaster areas. Some drones and motorcycles are deemed to collect the information. Also, some repair groups are considered to increase the reliability of blocked routes.

In the rest of paper, in section 2 previous papers about humanitarian supply chain are studied, additionally, the paper's innovation is determined. The problem definition and the mathematical model have been explained in section 3. The solution method is presented in section 4. Section 5 consists of numerical examples, parameter tunings and model validation sections. The results are presented, examined and discussed in section 6. Finally, the conclusion is explained in section 7.

Literature Review

Some investigations have been reviewed in this section. They are categorized into two main segments and evaluated in Table 1.

Consideration of monitoring or reliability of route

Monitoring the routes to collect information is one topic that is evaluated in this paper. Monitoring is considered to collect information about demand points and routes in previous papers. Reliability of route is another topic evaluated in the humanitarian relief supply chain. Three stages were discussed in [4]. In the mentioned paper, several kinds of vehicles were used for transferring relief items (Collecting information about disaster areas, planning for transferring items and considering infrastructure were three stages which discussed). Edrissi et al. [5] considered a transportation network reliability by considering a priority to each route and tried to survive people. Especial buses were sent to disaster areas. Each bus consists of one doctor, five nurses, three dogs, and food. Huang et al. [6] modeled multiple humanitarian objectives. It focused on minimum delay cost, maximum lifesaving utility and transfer items with fairness. Oruc and Kara [2] in another paper just pay attention to monitoring and reliability of routes in disaster. It determined how to collect information about the reliability of routes for supply chains' manager. Torabi et al. [7] used an integrated scheme to repair routes and warehouses post-disaster to reduce the rate of casualty. Alagheh Band et al. [8] presented a model to maximize the gain from assessing the areas and roads and the minimum cover of roads and sits.

Satisfying demands Without consideration of monitoring or reliability of route

In some papers like [9], multiple purposes were discussed. Minimum shortage and cost and maximum affected area's satisfaction were three objectives. it presented an efficient model for humanitarian relief. Döyen et al. [10] considered a two-echelon supply chain that investigates the logistic problem and looked for the best solution to the problem in search of minimization cost (inventory, facility, transportation, and shortage). Moreover, several kinds of relief items were transferred to disaster areas. Galindo and Batta [11] designed an effective strategy for the hurricane. It considered two stages, the first stage investigated potential distributions and chose the best locations where distributions were built, and the second stage focused on routing problem and transfer relief items to disaster areas. A limited budget was considered, too. Chang et al. [12] is another research that tried to reduce unsatisfied demands, response time and logistic cost by finding the best strategy. The time window was considered by [13]; if delivery time were more than a specific time, a significant penalty would consider for the objective function. It was a food industry and investigates routing with several kinds of vehicles. Several networks like shelters, medical and distribution were considered [14]. Minimum travel distance and operation cost and psychological were the paper's objectives, and it tried to satisfy these objectives. The effect of information technology on the humanitarian supply chain was shown [15]. Information technology can improve the efficiency of the relief supply chain. A quick response was an aim [16] . This paper tried to allocate resources and facilities efficiently. It considered the penalty for delay in delivery time and limited capacity distributions. Ruan et al. [17] considered a fuzzy number and finally demonstrated the fuzzy approach for relief items allocation in disaster. This research focused on disaster response on a large scale.

Tofighi et al. [18] researched pre-and post-disaster. In the first step, it searched about establishing distributions that were limited capacity, and in the second step, this research focused on transferring relief items. Its chief objective of this paper was to minimize transfer time and allocates weight for essential relief items. Different post-disaster challenges were discussed [19]. This paper analyzed the post disaster’s challenges by solving three objectives. Cantillo et al. [20] emphasized that humanitarian relief supply chains must guaranty quick response and transfer vital items as soon as possible. Rezaei-Malek et al. [21] considered a different cost for ambulance routing and do their best to reduce cost and time. [22] presented the role of option contract in pre-disaster for the satisfying vaccine in post-disaster. Tavana et al. [23], like previous researches, considered humanitarian relief items supply chain and minimized cost for establishing warehouses before the disaster occurs and for transferring items and then reduces response time. In Cotes and Cantillo [24], the cost was a key factor; limited capacity vehicles transfer relief items to disaster areas and the chief objective of this paper was to minimize total costs. Inventory cost, transfer cost and fix cost for establishing distributions were considered. Some important questions about humanitarian relief items were replied [25]. This investigation answered "how to transfer relief items to disaster areas" and discussions about the use of vehicles, because it considered a different kind of vehicles: especial vehicles and regular vehicles. Also, it was considered a kit for relief operations. Abazari et al. [26] introduced a multi-objective mathematical model with several uncertain parameters to study prepositioning and distributing relief items in a humanitarian supply chain.

Some of the above papers that are related to our investigation are evaluated in Table 1. It is clear that papers that investigated the monitoring or reliability of the route were not as paid attention as papers investigating quick response in disasters. Features and objectives are the main segments discussed, and finally, they compare with this research. According to Table 1, monitoring, quick response, route, and repair groups' reliability are considered in the feature segment, and reliability, response time, monitoring time, and satisfying demand are discussed in the objective segment. This study focuses on these features and objectives, which help the research to be more efficient. Some parameters are not exact, and it is determined approximately by experts or vehicles, so this paper uses fuzzy parameters when faces with these problems (ranking function is used).

Table 1. Related recent papers in humanitarian relief supply chain

Reference	**Features**	**Objective**						
	Monitor-ing	Quick response	Reliability of route	Repair groups	reliability	Response time	Monitoring time	Satisfied demand
This study	√	√	√	√	√	√	√	√
[12]	-----	√	-----	-----	-----	√	-----	√
[4]	√	√	-----	-----	-----	√	√	-----
[14]	-----	√	-----	-----	-----	√	-----	√
[5]	-----	√	√	-----	√	√	-----	-----
[6]	-----	√	-----	-----	√	-----	√	-----
[8]	-----	√	-----	-----	-----	√	-----	√
[1]	-----	√	-----	-----	-----	√	-----	√
[2]	√	-----	√	-----	-----	-----	√	-----
[20]	-----	√	-----	-----	-----	√	-----	-----
[7]	-----	√	√	√	√	√	-----	√
[24]	-----	√	-----	-----	-----	√	-----	√
[25]	-----	√	-----	-----	-----	√	-----	√

The previous investigations are evaluated in two segments: Features and Objective. Consideration of monitoring routes, reliability of the route, and repair groups are less paid attention to by researchers. According to Table 1, monitoring of demand points, quick response for satisfying demands, and increasing routes' reliability were not considered simultaneously. Previous researches evaluated mentioned topics separately. This paper's novelty is considering different stages, monitoring routes after a disaster for collecting information in the first stage. Then repair groups start their activities to increase routes' reliability for transferring relief items by using fuzzy parameters. In this research, drones and motorcycles are used for collecting information (route's reliability, the average distance between distributions, and disaster areas and demands in disaster areas), this operation determines initial parameters and there is not a lake of understanding of how initial parameters are obtained. After determining initial parameters, repair groups are sent to routes that are selected for the operation to boost the route's reliability due to the decreasing rate of new casualties. The above stages are used for efficient humanitarian relief supply chain and fill determined research gaps. The main motivation of the authors about writing this paper is representing an efficient model that can help emergency departments to improve infrastructure for a decreasing rate of casualty when disasters happen. For the increasing effect of the model, some stages like monitoring the routs for collecting information, repair groups for increasing the reliability of routs, and transferring relief items are considered.

Problem definition

Humanitarian relief's problem in this study has four different stages:

At the first stage, when a disaster is reported, drones and motorcycles start to monitor and collect information from routes that reach a disaster area or cities [2]. Due to the importance of the first stage's output, the tradeoff between cost and time is not considered and we just focus on reducing monitoring time; also its cost is ignored.

After collecting information, they send them to the manager, and he/she evaluates the information. Then, he/she sends repair groups to repair the routes. Monitoring is very critical in the first stage and helps recognize the situation profoundly and take measures effectively. The second stage is about warehouses and distributions. After drones and motorcycles do their duty and evaluating information among potential distribution candidates, appropriate choices are selected. Therefore, distributions are built in appropriate locations for delivering relief items to disaster areas in a short time. This stage is a basic element of the humanitarian relief supply chain and other activities related to this stage. Some potential locations exist and by evaluating information, some potential distributions are selected for transferring relief items among all potential locations.

The third stage uses two previous stages and decides whether roads need reparation or not? If roads need to repair, repair groups will be sent to repair roads and increase the reliability of them. If roads don't need to repair, the humanitarian relief operation will start and relief items are sent to disaster areas by distributions. After the above stages, the relief item distribution is begun. Relief items are sent from warehouses to disaster areas, as soon as possible. Transferring relief items by roads that have high reliability is so safe.

Some parameters are not certain and it is determined approximately by experts or vehicles, so this paper uses fuzzy parameters when faces with these problems (Ranking function is used).

Two scenarios are considered in the allocation relief item approach, based on Noham and Tzur [1]. These two scenarios are prevalent scenarios in the humanitarian supply chain; thus they are considered in our investigation. 1) Equitable allocation: This scenario shares relief items with fairness. 2) Preferred assignment: It emphasizes that every demand point must receive relief items from the closest distribution. The closest distribution means that the distribution which transfers items sooner than others not just based on distance. By this approach, it is possible that the ratio of some demand points' satisfied demand becomes higher than the others. A service level gap) δ (is introduced to help to maximize the ratio of satisfied demand in all demand points for each scenario.

The information provided in the first stage of the model is related to the condition of the roads and the depth of the disaster in the cities. Disaster management determines the probability of each scenario based on the collected information. Because the information collected in the first stage estimates the situation observation, the manager could assert we use this scenario by this probability. Then, the outputs of the models show both scenarios' decision variables by using the effect of their probability, and finally, the manager selects the appropriate strategy.

Road or routes are made safe for transferring relief items to disaster, and vehicles cannot use roads until roads' reliability becomes one [3]. This approach prevents accident or occurrence another disaster or on the other word, reduce the probability of damaging equipment and people.

Fig. 1 illustrates four stages of all operations in our model. The first phase of our operations is modeled separately from another phase. The first stage has a vital role in our operations and without this stage, the second phase cannot be started. The second phase consists of three stages and this phase is modeled separately from the first phase and tries to satisfy demands in demand points.

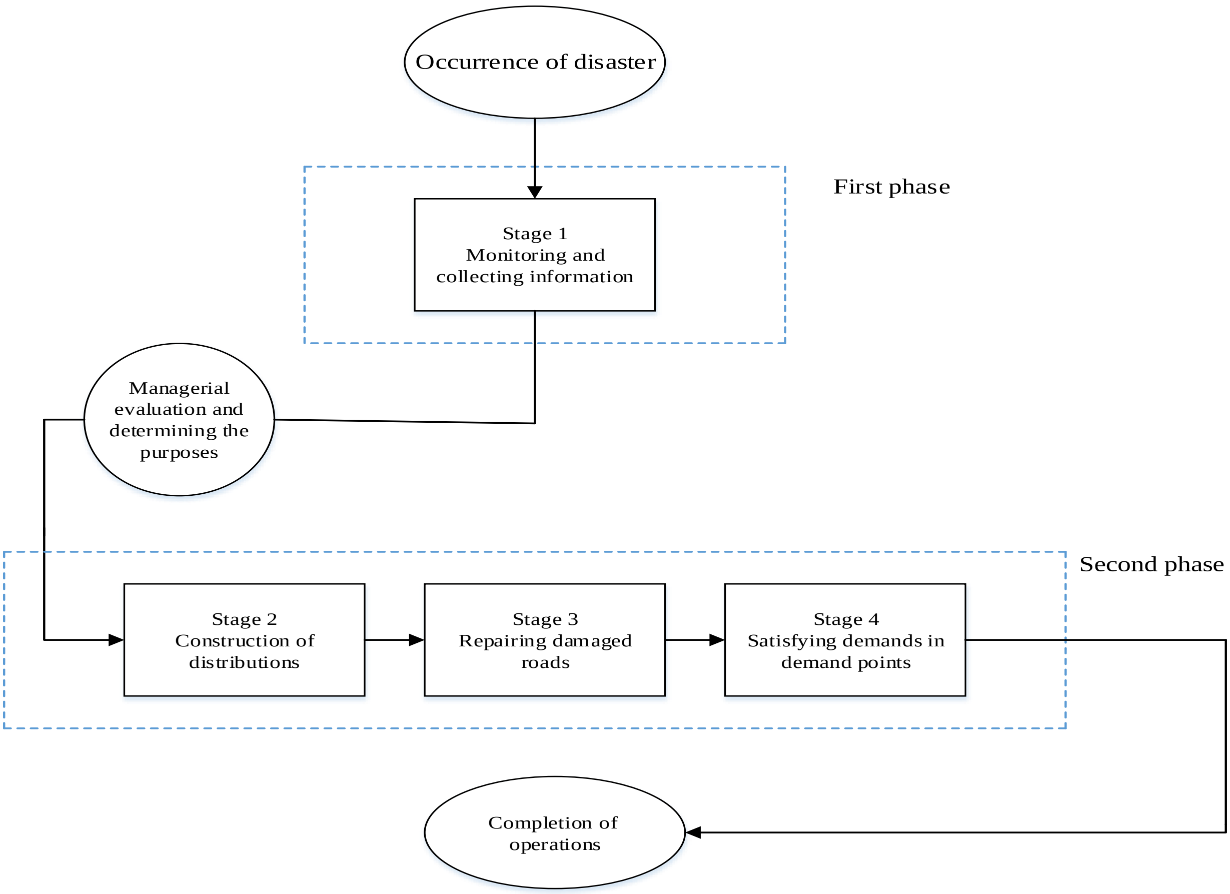

Fig. 1. Schematic of all operations

Assumption

The following assumptions have been considered to develop the model:

- Relief item's vehicles are not permitted to start operation until the reliability of the route is becoming one [3].
- Total response time may be increased due to repair time is more than the time that relief items arrive at distribution [2].

To simplify modeling, the following assumptions are also considered:

- The shortage of drones, and motorcycles is not considered.
- Each demand point has to be satisfied with one distribution.
- One repair group is enough to increase the reliability of damaged routes.
- Three-time points are considered. T0 shows the moment that the disaster happened. T1 is the time that information is collected completely and repair group activities are done, T2 is the point time that satisfying demand operation is begun.

Nomenclature

Sets

I	Set of potential warehouses sites
J	Set of potential distribution centers
K	Set of demand points
S	Set of scenarios
T	Set of time
G	Set of group repairs
V	Set of motorcycles and drones = $Mo_v \cup Dr_v$
Mo_v	Set of motorcycles
Dr_v	Set of drones

Parameters

c_j	The capacity of distribution j
NI	Number of warehouses to open
δ	Service level gap
M	Big number
Di	Number of disaster areas
Dis	Number of distribution points
Nm	Number of motorcycles
Nd	Number of drones
NJ^s	Max number of distributions to open under scenario s
P^s	Probability of occurrence each scenario
d_k^s	Demand at location k under scenario s
l'_{ij}	Distance between warehouse i to distribution j
l_{jk}	Distance between distribution j to demand k
r_{0jk}	Initial reliability between distribution j to demand k
Mon_{jkmo}	Monitor time between distribution j to demand k by motorcycle
Mon_{jkdr}	Monitor time between distribution j to demand k by drones

Decisions variables

U_i^s	Equal one if warehouse i open under scenario s
x_{jk}^s	Number of the unit allocated distribution j to k, under scenario s

x_k^s	Number of the unit allocated to demand k under scenario s
RT_{jk}^s	Total response time under scenario s
r_{jkts}	Reliability of road between j and k in the period of t
add_{jk}	Additive time for reliability between j and k
MT_{jkv}	Monitor time between distribution j and demand k
Y_j^s	Equal one if distribution j open under scenario s
$T_{ij}^{\prime s}$	Equal one if distribution j assigned to warehouse i
T_{jk}^s	Equal one if demand k assigned to distribution j, under scenario s
w_{jktgs}	Equal one if gth group repair ((jk)) at period (t-1)
xm_{jkmo}	Equal one if the road between j and k is monitor by motorcycle
xd_{jkdr}	Equal one if the road between j and k is monitor by drone

Mathematical model and further explanations

First phase mathematical model

The first phase is modeled separately from the rest of the stages and its collected information is used as the parameters for the rest stages.

In this section, the fuzzy mathematical model for the first stage which is labeled "First model" is presented as follows:

$$Min \quad \sum_{j\in J}\sum_{k\in K}\sum_{v\in V} MT_{jkv} \tag{1}$$

$s.t$

$$\sum_{mo\in Mo}\sum_{k\in K}\sum_{j\in J} xm_{jkmo} = Nm \tag{2}$$

$$\sum_{dr\in Dr}\sum_{k\in K}\sum_{j\in J} xd_{jkdr} = Nd \tag{3}$$

$$MT_{jkv} = xm_{jkmo}\times \tilde{M}on_{jkmo} + xd_{jkdr}\times \tilde{M}on_{jkdr} \qquad \forall j\in J, k\in K, v\in V, mo\in Mo, dr\in Dr \tag{4}$$

$$\sum_{mo\in Mo}\sum_{k\in K}\sum_{j\in J} xm_{jkmo} + \sum_{dr\in Dr}\sum_{k\in K}\sum_{j\in J} xd_{jkdr} = Di\times Dis \tag{5}$$

$$\sum_{mo\in Mo} xm_{jkmo} \le 1 \tag{6}$$

$$\sum_{dr\in Dr} xd_{jkdr} \le 1 \tag{7}$$

$$\sum_{j\in J}\sum_{k\in K} xm_{jkmo} = 1 \qquad \forall mo\in Mo \tag{8}$$

$$\sum_{j\in J}\sum_{k\in K} xd_{jkdr} = 1 \qquad \forall dr\in Dr \tag{9}$$

$$xm_{jkmo} + xd_{jkdr} \le 1 \qquad \forall j\in J, k\in K, mo\in Mo, dr\in Dr \tag{10}$$

$$xm_{jkmo}, xd_{jkdr} \in \{0,1\} \tag{11}$$

$$MT_{jkv} \geq 0 \tag{12}$$

Eq. 1 focuses to minimize monitoring time (first stage), it is the objective function for the first stage. Constraints (2-10) are related to the first stage and focuses on allocating motorcycles and drones to each road for monitoring. Eqs. 2 and 3 illustrate the equation of motorcycles and drones which are allocated to roads. Constraint (4) determines the total monitoring time. Eq. 5 shows that every route or road must visit by monitoring, (6) and (7) show that each route must visit by a maximum of one motorcycles or drones. Obligation visiting every route is satisfied by (8) and (9), constraint (10) defines that one motorcycle or one drone is allocated to each route. Finally, (11) and (12) shows which variables are binary and which variables are positive.

Second phase mathematical modeling

Now, the fuzzy mathematical model for the second phase which is labeled "Second model" is presented as follows:

$$Max \quad \sum_{s \in S} p^s \sum_{j \in J} \sum_{k \in K} x_{jk}^s \tag{13}$$

$$Min \quad \sum_{s \in S} p^s \sum_{j \in J} \sum_{k \in K} RT_{jk}^s \tag{14}$$

$$Max \quad \sum_{j \in J} \sum_{k \in K} \sum_{t \in T} \sum_{s \in S} r_{jkts} \tag{15}$$

$$s.t$$

$$x_{jk}^s \leq c_j \times T_{jk}^s \quad \forall j \in J, k \in K, s \in S \tag{16}$$

$$\sum_{k \in K} x_{jk}^s \leq c_j \quad \forall j \in J \tag{17}$$

$$x_k^s = \sum_{j \in J} x_{jk}^s \quad \forall k \in K, s \in S \tag{18}$$

$$x_k^s \leq \tilde{d}_k^s \quad \forall k \in K, s \in S \tag{19}$$

$$\frac{x_k^s}{\tilde{d}_k^s} \leq \frac{x_m^s}{\tilde{d}_m^s}.\delta \quad \forall k \in K, m \neq k, s \in S \tag{20}$$

$$\frac{x_k^s}{\tilde{d}_k^s} \leq \frac{x_m^s}{\tilde{d}_m^s} + (2 - T_{jk}^s - T_{jm}^s) \quad \forall j \in J, k \in K, m \neq k, s \in S \tag{21}$$

$$\tilde{l}_{jk} \times T_{jk}^s \leq \tilde{l}_{hk} \times Y_h^s + M.(1 - Y_h^s) \quad \forall j \in J, k \in K, h \neq j, s \in S \tag{22}$$

$$\sum_{j \in J} T_{jk}^s = 1 \quad \forall k \in K, s \in S \tag{23}$$

$$T_{jk}^s \leq Y_j^s \quad \forall j \in J, k \in K, s \in S \tag{24}$$

$$\sum_{j \in J} Y_j^s \leq NJ^s \quad \forall s \in S \tag{25}$$

$$\sum_{i \in I} T_{ij}'^s = 1 \quad \forall j \in J, s \in S \tag{26}$$

$$T'^{s}_{ij} \le U_i \quad \forall j \in J, i \in I, s \in S \tag{27}$$

$$\sum_{i \in I} U_i \le NI \tag{28}$$

$$r_{jkts} \le \tilde{r}_{0jk} + w_{jktgs}(1-\tilde{r}_{0jk}) + M.(1-T^{s}_{jk}) \quad \forall j \in J, k \in K, t \in T, g \in G, s \in S \tag{29}$$

$$r_{jkts} \ge \tilde{r}_{0jk} + w_{jktgs}(1-\tilde{r}_{0jk}) - M.(1-T^{s}_{jk}) \quad \forall j \in J, k \in K, t \in T, g \in G, s \in S \tag{30}$$

$$r_{jkts} \le \tilde{r}_{0jk}(1-T^{s}_{jk}) + T^{s}_{jk} \quad \forall j \in J, k \in K, s \in S \tag{31}$$

$$w_{jk,t=0,gs} = 0 \quad \forall j \in J, k \in K, s \in S \tag{32}$$

$$r_{jk,t=0,s} = \tilde{r}_{0jk} \quad \forall j \in J, k \in K, s \in S \tag{33}$$

$$add^{s}_{jk} = Max\{T^{s}_{jk}(rep_{jk}) - \tilde{l}'_{ij}, 0\} \quad \forall i \in I, j \in J, k \in K, s \in S \tag{34}$$

$$RT^{s}_{jk} = \sum_{i \in I}(T'^{s}_{ij} \times \tilde{l}'_{ij}) + T^{s}_{jk} \times \tilde{l}_{jk} + add^{s}_{jk} \quad \forall j \in J, k \in K, i \in I, s \in S, \tag{35}$$

$$U_i, Y^{s}_{j}, T'^{s}_{ij}, T^{s}_{jk}, w_{jktgs} \in \{0,1\} \tag{36}$$

$$x^{s}_{jk}, x^{s}_{k}, RT^{s}_{jk}, add_{jk} \ge 0 \tag{37}$$

$$0 \le r_{jkts} \le 1 \tag{38}$$

Eqs. 13-15 are objective functions. The objective function (13) is looking for maximizing satisfied demand in each area. Eq. 14 tries to minimize total response time and Eq. 15 maximizes reliability. Constraints (16-28) are made in the second and fourth stages. Eq. 16 states that relief items are sent by distribution if and only if route (jk) is selected for transfer. Constraint (17) does not permit the total quantity of product to exceed the distribution's capacity. Eq. 18 shows that amount relief items are sent to the demand point and (19) does not permit those relief items which are sent to demand points become more than the demand point's demands. Eq. 20 defines the service gap, i.e. the maximal ratio (denoted by δ) between the proportions of satisfied demand at all demand points. And constraint (21) states that all demand points that are served by the same distribution will receive equal proportions of their demand. Constraint (22) ensure that each demand point is allocated to the closest distribution. Constraint (23) shows that each demand point is allocated to one distribution and (24) ensures that relief items are sent by distribution if it is open. Constraint (25) shows how many distributions are permitted to establish and (26) ensures that one warehouse must allocate to each distribution. Eq. 27 states that established warehouses must send relief items to distribution and (28) shows that how many warehouses must establish. Constraints (29-35) are determined by the third stage. Eq. 29 and 30 state that the reliability of each road and these constraints illustrate that if route (jk) is selected for transferring relief items, repair groups could do their operation on this route. Constraint (31) shows that if route (jk) is selected for transferring relief items, reliability of route (jk) will become one at end of period t, and if route (jk) is not selected for transferring relief items, reliability of route (jk) will be equal initial reliability. Eqs. 32 and 33 determine at end of the first period, allocating repair groups is not done and the reliability of each route is equal to initial reliability due to monitoring operations are not done. Constraint (34) determines the additive time for each route if repairing time is more than transferring relief items time from warehouse i to distribution j, this variable becomes more than zero. Eq. 35 calculates response time from warehouses to demand points after the information is sent by monitoring groups.

Finally, (36) and (37) show that which variables are binary and which variables are positive, and (38) determines the range of changing reliability.

Ranking function

As mentioned before, some parameters like time and distance consider the fuzzy number because these parameters cannot determine certainly. According to the mathematical model mentioned in section 3, some equations have fuzzy parameters. To make them non-fuzzy parameters fuzzy ranking function is used:

$$g(\tilde{a}) = \frac{\int_{a^l}^{a^u} x.\mu_{\tilde{a}}(x)dx}{\int_{a^l}^{a^u} \mu_{\tilde{a}}(x)dx}; \quad if \quad \tilde{a} \cong TFN(a_1, a_2.a_3) \rightarrow g(\tilde{a}) = \frac{1}{3}(a_1 + a_2 + a_3) \tag{39}$$

In the above formula, a^u and a^l illustrate two final numbers of the range $\mu_{\tilde{a}}(x)$ (Yager 1979).

Now by using the mentioned function, the constraints (4), (19)-(22), (29)-(31), (33)-(35) are rewritten respectively, as follows:

$$MT_{jkv} = xm_{jkmo} \times (\frac{Mon_{jkmo1} + Mon_{jkmo2} + Mon_{jkmo3}}{3}) + xd_{jkdr} \times (\frac{Mon_{jkdr1} + Mon_{jkdr2} + Mon_{jkdr3}}{3}) \quad \forall j \in J, k \in K, v \in V, mo \in Mo, dr \in Dr \tag{40}$$

$$x_k^s \leq (\frac{d_{k1}^s + d_{k2}^s + d_{k3}^s}{3}) \quad \forall k \in K, s \in S \tag{41}$$

$$\frac{3 \times x_k^s}{d_{k1}^s + d_{k2}^s + d_{k3}^s} \leq \frac{3 \times x_m^s}{d_{m1}^s + d_{m2}^s + d_{m3}^s}.\delta \quad \forall k \in K, m \neq k, s \in S \tag{42}$$

$$\frac{3 \times x_k^s}{d_{k1}^s + d_{k2}^s + d_{k3}^s} \leq \frac{3 \times x_m^s}{d_{m1}^s + d_{m2}^s + d_{m3}^s} + (2 - T_{jk}^s - T_{jm}^s) \quad \forall j \in J, k \in K, m \neq k, s \in S \tag{43}$$

$$\frac{l_{jk1} + l_{jk2} + l_{jk3}}{3} \times T_{jk}^s \leq \frac{l_{hk1} + l_{hk2} + l_{hk3}}{3} \times Y_h^s + M.(1 - Y_h^s) \quad \forall j \in J, k \in K, h \neq j, s \in S \tag{44}$$

$$r_{jkts} \leq \frac{r_{0jk1}+r_{0jk2}+r_{0jk3}}{3} + w_{jktgs}(1-\frac{r_{0jk1}+r_{0jk2}+r_{0jk3}}{3}) + M.(1-T_{jk}^{s}) \quad \forall j \in J, k \in K, t \in T, g \in G, s \in S \tag{45}$$

$$r_{jkts} \geq \frac{r_{0jk1}+r_{0jk2}+r_{0jk3}}{3} + w_{jktgs}(1-\frac{r_{0jk1}+r_{0jk2}+r_{0jk3}}{3}) - M.(1-T_{jk}^{s}) \quad \forall j \in J, k \in K, t \in T, g \in G, s \in S \tag{46}$$

$$r_{jkts} \leq \frac{r_{0jk1}+r_{0jk2}+r_{0jk3}}{3} \times (1-T_{jk}^{s}) + T_{jk}^{s} \qquad \forall j \in J, k \in K, s \in S \tag{47}$$

$$r_{jk,t=0,s} = \frac{r_{0jk1}+r_{0jk2}+r_{0jk3}}{3} \qquad \forall j \in J, k \in K, s \in S \tag{48}$$

$$add_{jk}^{s} = Max\{T_{jk}^{s}(rep_{jk}) - \frac{l_{ij1}+l_{ij2}+l_{ij3}}{3}, 0\} \qquad \forall i \in I, j \in J, k \in K, s \in S \tag{49}$$

$$RT_{jk}^{s} = \sum_{i \in I}(T_{ij}'^{s} \times \frac{l_{ij1}+l_{ij2}+l_{ij3}}{3}_{ij}) + T_{jk}^{s} \times \frac{l_{jk1}+l_{jk2}+l_{jk3}}{3} + add_{jk}^{s} \quad \forall j \in J, k \in K, i \in I, s \in S, \tag{50}$$

Solution methods

In the rest of the study, three problems with different information and dimensions (one small scale, one medium scale, and a big scale) are considered and solved, and at the end of each scale, results are compared.

Small scale and medium scale problems are solved by GAMS. The model has four objectives, so a method needs to solve this kind of problem. LP- metrics technique is one approach for solving multi-objectives problems. This approach does its best to minimize the gap between optimal results and the multi-objective's result.

LP-metric's form is presented below:

$$L_p = [\sum_{k=1}^{K} (\pi_k |W_k - b_k|)^p]^{\frac{1}{p}} \tag{49}$$

In the above formula, p determines which family of LP-metric is used, and πk shows each objective's weight and the rest of the formula shows the gap between optimal result and the multi-objective's result [27].

Then the big scale is solved by Grasshopper Optimization Algorithm (GOA). [28] presented the GOA which is a recent metaheuristic optimizer. The efficiency of the metaheuristic algorithm will determine in the big scale section by comparing the metaheuristic result and GAMS results in small and medium scale. Taguchi technique is used for tuning parameters for increasing the efficiency of results. All parts mentioned above, are shown in the rest of the study. GOA is inspired by the behavior of grasshopper swarms in the real-world and is mimicked the repulsion among the grasshoppers. The grasshoppers often hurt the crops which are obtained from agriculture, and this fact has a deep impact on people's belief which they consider them as a pest. Most of the time the grasshopper is seen individually in nature but usually, grasshoppers join vast swarms between all animals in the world. They eat their target food which is grown in their route with their movements. They usually migrate far distances. The swarm often moves slowly when they have dire problems in the larval phase. The chief reason for gathering grasshopper together is that they search for finding the source of food that this kind of search is unique. GOA algorithm uses this feature of grasshoppers to find the optimal answer [29].

Numerical example

Computational experiments

In this section, an exact approach is used for small and medium scales, and the metaheuristic approach is used for a big scale. Small and medium scale results are obtained by the exact method (GAMS). ANTIGONE solver is used for solving small and medium scale. The exact method is so efficient for small and medium scales since it can solve the model at the appropriate time with exact results. Still, this method cannot solve a big scale since the solver needs inappropriate time, so the GOA is used as a meta-heuristic algorithm for solving a big scale. The metaheuristic algorithm can solve the big scale at the appropriate time with a small gap.

Small-scale problem

To evaluate the model, one problem is prompted and its data which is used for small scale is considered in Table 2.

Table 2. Initial information of the small scale

sets	
set of potential warehouses sites	A,B
set of potential distributions	c,d,e
set of demand points	1,2,3
set of scenarios	s1,s2
set of time	t0,t1,t2
set of motorcycles and drones	m1,m2,m3,m4,m5,d1,d2,d3,d4

This example considers two warehouse sites and three potential distributions and demand points. Two scenarios are considered (Equitable allocation and preferred assignment). Set of times are explained in assumption and five motorcycles and four drones. Capacity of distributions are considered: c=50, d=50, e=40. The maximum number of warehouses to open is equal to 2, the service gap level is equal to 1.5. For the first scenario maximum distribution centers number is two and for the second is three and the probability of each of them in order is 0.4 and 0.6. Final numbers are written at tables that have fuzzy numbers. The first scenario is the equitable allocation and the second scenario is the preferred assignment.

The rest of the initial information is shown in Appendix A.

Medium-scale problem

In the medium scale, two warehouses, four distribution, and eight disaster areas are considered. The information is shown in Table 3.

Table 3. Initial information of the medium scale

sets	
set of potential warehouses sites	A,B
set of potential distributions	c,d,e,f
set of demand points	1,2,3,4,5,6,7,8
set of scenarios	s1,s2
set of time	t0,t1,t2
set of motorcycles	m1-m20
Set of and drones	d1-d12

This example considers two potential warehouse sites and four potential distributions and eight demand points. Two scenarios are considered (Equitable allocation and preferred assignment). Set of times are explained in assumption and twenty motorcycles and twelve drones. Capacity of distributions are considered: c=100, d=110, e=80, f=100. The maximum number of warehouses to open is equal to 2, the service gap level is equal to 1.5. For the first scenario, the maximum distribution center number is two and for the second is three, and the probability of each of them in order is 0.4 and 0.6. The first scenario is the equitable allocation and the second scenario is the preferred assignment.

The rest of the initial information is shown Appendix B.

Big-scale problem

For evaluating the problem on a big scale, a metaheuristic algorithm is required, and the GOA is used. 15 warehouses, 30 potential warehouses, and 50 demand points are considered for the big scale; like previous scales, big-scale parameters are determined, and GOA uses its best for solving the model. The big scale is so far closer to reality than previous scales, so selecting an efficient metaheuristic algorithm is necessary.

Parameters tuning

The Taguchi technique is used for tuning parameters. Taguchi's result for tuning some GOA's parameters like iteration, npop (the number of grasshoppers) are determined in Table 4.

Table 4. State table and Taguchi analyze parameters

	Iteration	Number of population
State 1	50	40
State 2	75	50
State 3	100	60

If the objective minimizes the variables, the lowest state is used and if the objective maximizes the variables, the highest state is used. According to Fig. 2, the best parameters which help to the efficiency of the algorithm, are selected to use in the algorithm (iteration =100, npop=50).

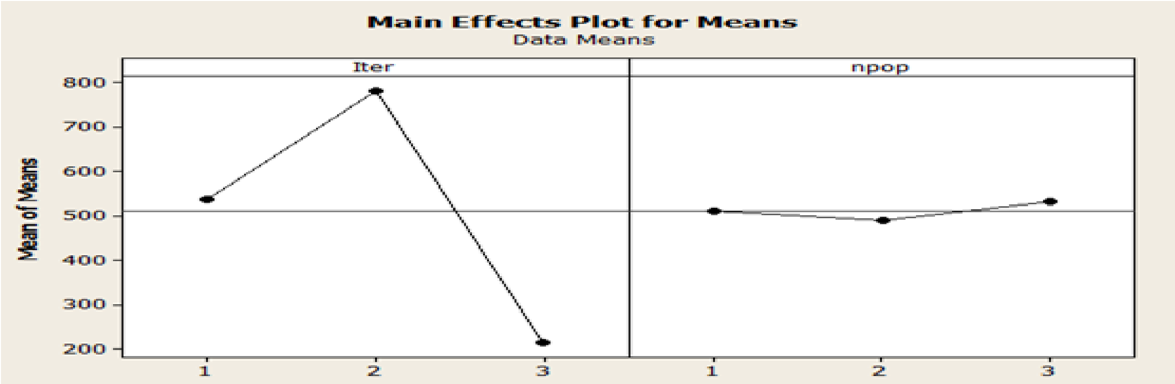

Fig. 2. Taguchi's result

The model validation is presented in Appendix C.

Results and discussion

Results

Now all parameters are determined and we solve this small example in GAMS to evaluate the efficiency of the model. The summary of the small-scale's results is shown in Table 5. As the results show, the model tries to satisfy all objectives, but it cannot satisfy all of them. Eq. 13-15 are called objective 1, 2, and 3 in order and Eq. 1 is called objective 4 in the results.

Table 5. Small scale's results

Test problem number	Weight of objective function				Objective function value			
	w1	w2	w3	w4	f 1	f 2	f 3	f 4
1	0.25	0.25	0.25	0.25	51.4	76	33	85
2	0.6	0.2	0.1	0.1	75	83	35	85
3	0.2	0.6	0.1	0.1	50	73	33	85
4	0.2	0.1	0.6	0.1	71.6	83	37	85
5	0.2	0.1	0.1	0.6	70	76	33	85

According to Table 5, the result at test problem 1, the weight of each objective is the same, and priority is not considered. As the above table shows, the first objective is not satisfied. In both scenarios, items are sent to each disaster points and. This gap is appeared due to the satisfying second objective. For minimizing response time, the solver selects warehouse B for sending relief items to distribution d in the first scenario and distributions d and e for the second scenario, they are close to warehouses and can satisfy the second objective; on the other hand, they do not have enough space for satisfying all demands, so fewer relief items are sent to disaster points. Objective three's results relate to routes that were selected, so it has different results. Objective four is independent of weight since it had done before humanitarian operations started, and it must visit all routes and selects the best way, and the best way is unique.

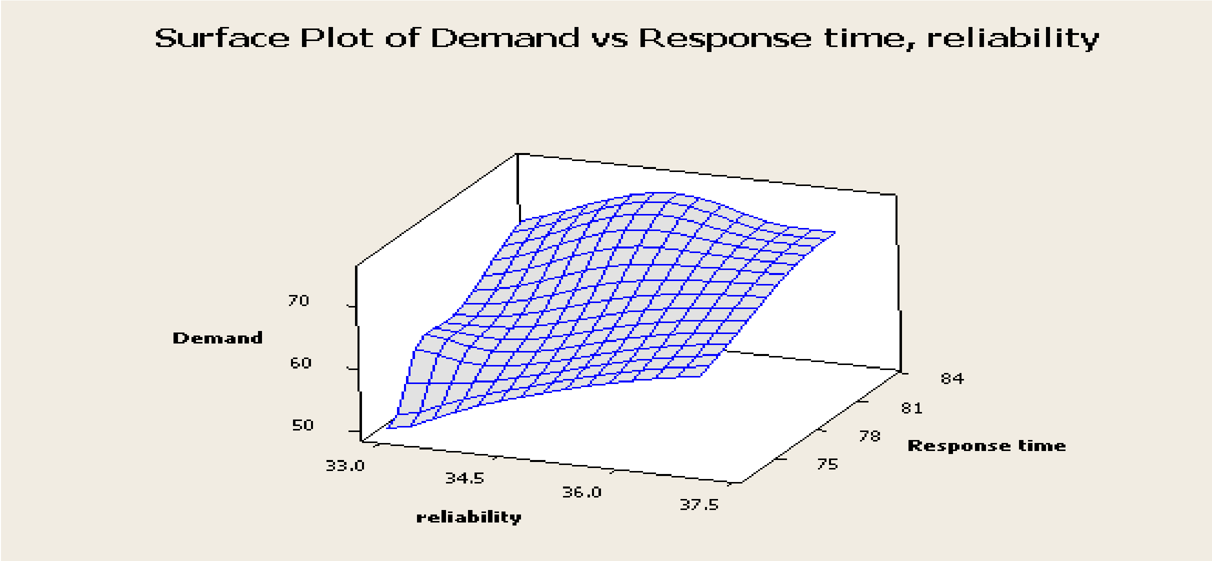

Fig. 3. Pareto diagram of small scale

In test problem 2, especial weight is considered for the first objective, this means the first objective has the highest priority.

Table 5 shows that all demands in disaster areas are satisfied, while closest distributions are not allocated to demand points in all cases. One distribution is allocated to a far demand point, due to the capacity of some distributions are not enough for satisfying all demands, so the model allocates the strategy which is not optimal, but satisfies the objective approximately.

All of the routes which are selected for transferring operation are repaired by repair groups, and this objective is satisfied completely. Monitoring operations are optimally done by motorcycles and drones, and the vehicles are allocated to each route with minimum monitoring time.

Fig. 4 shows the result of the model in the preferred assignment scenario. With one warehouse and two distributions, the humanitarian relief items supply chain completes its purpose. Satisfying demands is done completely, but the minimization of response time is not satisfied completely. In the monitoring stage, results are shown in Fig. 5.

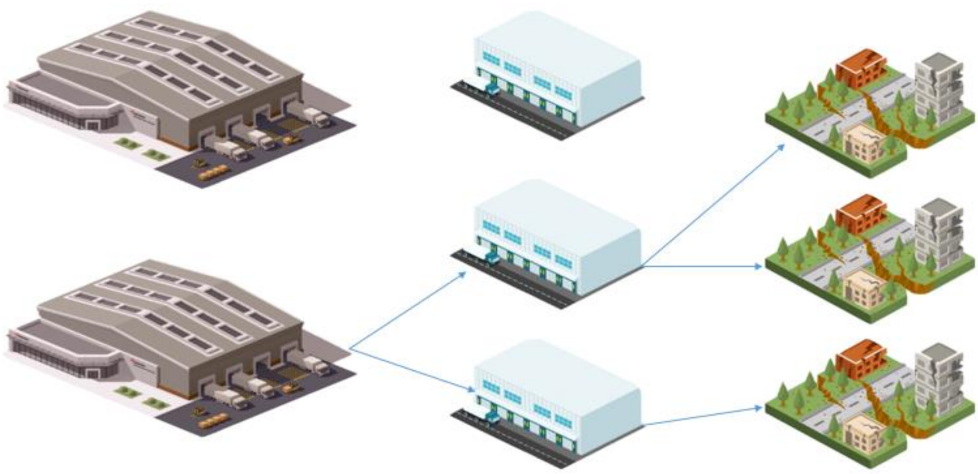

Fig. 4. Humanitarian relief items supply chain in preferred assignment scenario

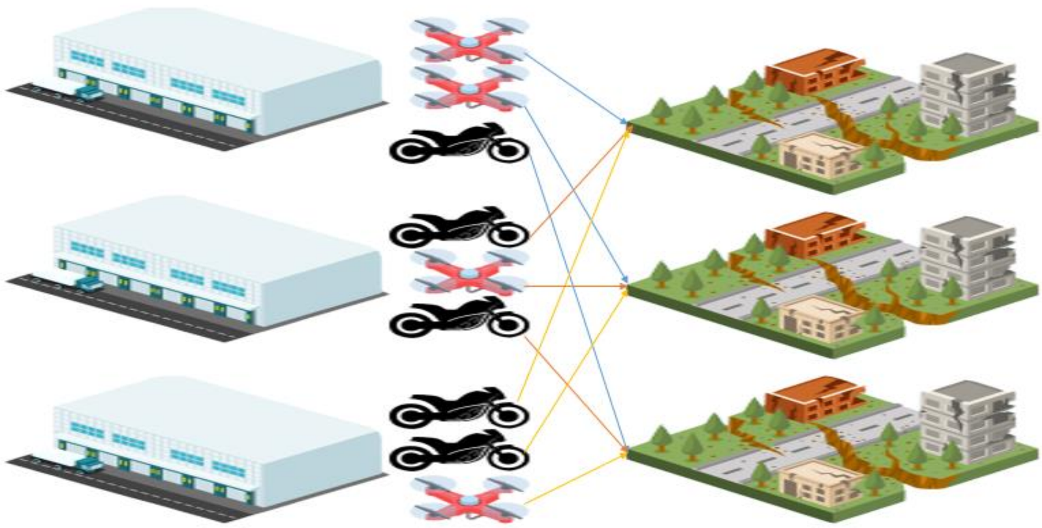

Fig. 5. Monitoring stage

Fig. 5 shows that the first distribution (c) sends drones for demand point number 1 and 2, and one motorcycle for monitoring route which is located between distribution c and demand point 3. For the other distributions, like c, other motorcycles and drones are sent for collecting information. This objective is satisfied completely. This paper assumes that shortage of drones and motorcycles is not allowed.

The summary of the medium-scale results is shown in Table 6. As a result show, the model does its best to satisfy all objectives, but it cannot satisfy all of them.

Table 6. Medium scale's results

Test problem number	Weight of objective function				Objective function value			
	w1	w2	w3	w4	f 1	f 2	f 3	f 4
1	0.25	0.25	0.25	0.25	187	244	88	77
2	0.6	0.2	0.1	0.1	200	253	87	77
3	0.2	0.6	0.1	0.1	184.3	239	88	77
4	0.2	0.1	0.6	0.1	187	246	89	77
5	0.2	0.1	0.1	0.6	189	244	87	77

Like the small scale, all objectives are not satisfied and objective four is independent of a priority since it is a separate stage and always has a unique result. Solver for satisfying the minimization of response time selects closest distributions, so the capacity of distributions is not considered and ample relief items are not sent to demand points. Other objectives are satisfied.

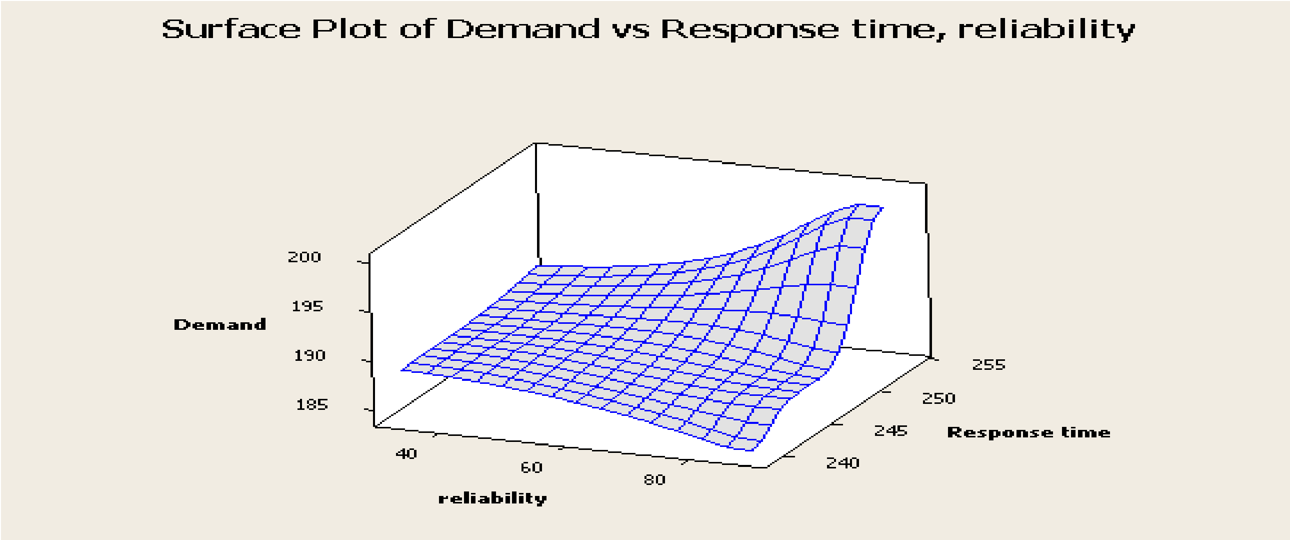

Fig. 6. Pareto diagram of medium scale

Fig. 6 shows Pareto's results, and we can see all results which are obtained are efficient but by different approaches. For instance test problem 2 does its best to satisfy demands in disaster areas and this approach is used when the time does not have a high priority, and test problem three is used when the time has a vital role, and all of these which is discussed, is considered by the manager and eventually, the manager chooses the best strategy by considering the situation.

For evaluating the metaheuristic algorithm's efficiency, we solve the small and medium scales for calculating the gap, between exact results and metaheuristic algorithm's result, then we compare results for calculating the gap which shows the efficiency of the algorithm in Table 7.

Table 7. Evaluating metaheuristic results

	Gams (small scale)	GOA (small scale)	Gap level	Gams (medium scale)	GOA (medium scale)	Gap level	Mean gap level
Objective 1	51.4	49.3	4%	187	172.04	8%	6%
Objective 2	76	76	0%	244	256.2	5%	2.5%
Objective 3	33	33	0%	88	88	0%	0%
Objective 4	85	88.4	4%	77	82	6%	5%
Total mean gap level							**4.5%**

According to Table 7, results show that GOA's gap is about 4.5 %, and this gap number proves that, this metaheuristic algorithm has ample efficiency for solving the problem on the big scale. Therefore, for real cases, that have a big scale, GAMS is not an appropriate solution method and we could use GOA by 4.5% gap. The small scale problem is solved by Gams in 00:55, and it is solved by GOA in 1:30. Moreover, the medium-scale problem is solved by Gams and GOA in order in 3:00 and 1:25. This data shows that the increasing size of the problem causes the time of solving the problem by Gams to boom exponentially.

One problem with 15 warehouses, 30 distributions, and 50 demand points is considered with its parameters. Table 8 shows the results. It was mentioned that solvers can't satisfy all objectives, but they do their best to satisfy the demand to the extent possible, so GOA does its best to reach the most efficient answer. The big-scale problem is not solved by GAMS in an hour, while it is solved by GOA in 4:00. Thus, for real cases, GAMS could not be used and be helpful and GOA is an appropriate solution method for solving the problem (See Appendix E).

Table 8. Big scale's results

Test problem number	Weight of objective function				Objective function value			
	w1	w2	w3	w4	f 1	f 2	f 3	f 4
1	0.25	0.25	0.25	0.25	469	1490	561.7	303.4
2	0.6	0.2	0.1	0.1	480	1496	563.3	303.4
3	0.2	0.6	0.1	0.1	462	1485	562.4	303.4
4	0.2	0.1	0.6	0.1	467	1494	263	303.4
5	0.2	0.1	0.1	0.6	470	1494	561	303.4

As results are shown in Table 8, objectives 1 and 2 might have contrast, and it is dependent on parameters. Objective 4 is independent and relates to a different stage of the humanitarian relief supply chain. It is obvious that by considering a priority for objectives, different results are obtained, so it depends on the manager's decision.

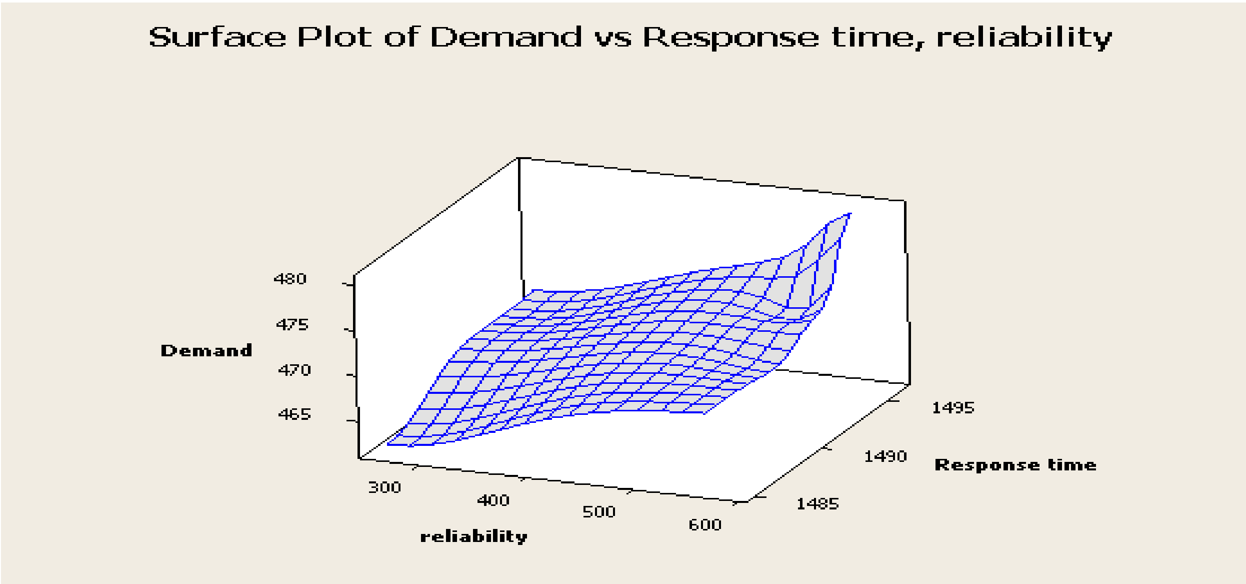

Fig. 7. Pareto diagram of big scale

According to Fig. 7, the best approach to satisfying the first objective is 2; this number maximizes number one. To meeting the second objective, number three must be used, and to satisfying the third objective, the first approach should be considered. The fourth objective is independent, and its result is never changed.

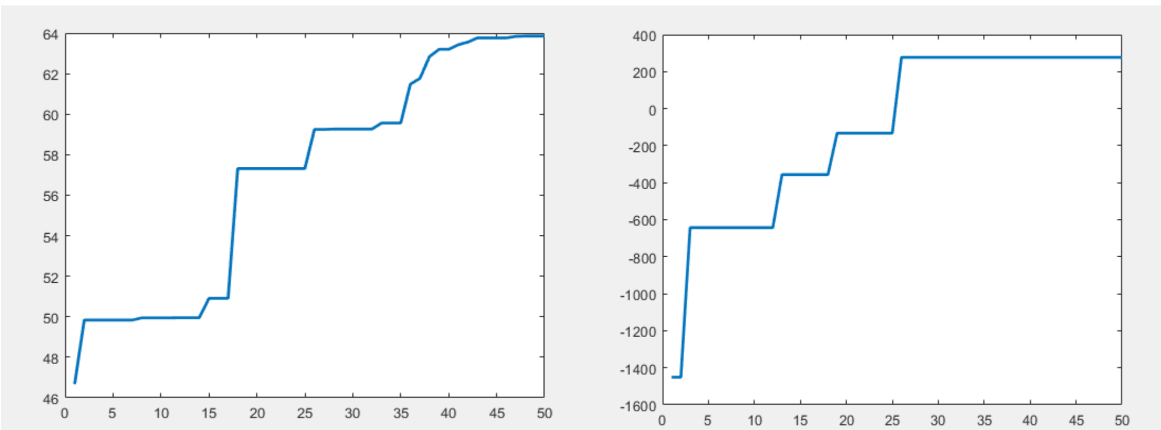

Fig. 8. First objective Convergence diagrams (Left diagram: small scale, right diagram: medium scale)

Fig. 8 shows GOA’s performance for the first objective (without other objectives) in small and medium scale with different parameters. This objective maximizes satisfying demand at demand points.

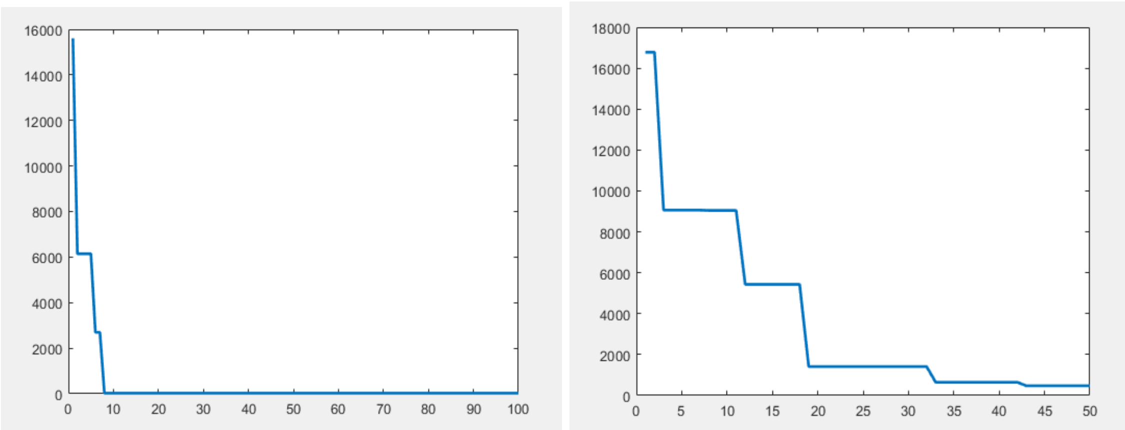

Fig. 9. Integration objective Convergence diagrams (Two diagrams show two different outputs of GOA)

GOA's performance is shown for all objectives in Fig. 9. In this section, the solver minimizes the gap between optimal results of each objective with that objective on a big scale. GOA's results prove that they are efficient and reliable, so they can present an efficient model for humanitarian relief supply chain problems.

Sensitivity analysis

In this section, some vital parameters are determined, and we will show the impact of them on results and strategy which is decided by the solver.

Fig. 10 shows the objective values (medium scale) when the probability of scenarios is changed. As the results are shown, the maximum of the first objective appears in 0.4 and the minimum of the first objective appears in 0.6, this means that the solver can use this method for giving high priority to the first objective. The optimal result for the second objective appears in 0.6, but as the chart shows, this number does not satisfy the first objective. In the previous section, one method is explained for considering the priority of objectives (allocating weight to each objective), but now the above analysis proves that the probability of occurrences in each scenario has the same effect on satisfying objectives, so using this method is helpful. The third objective's results have been changing but its change is very low. According to Fig. 10, results show that each scenario has a different output with different efficiency, so selecting the appropriate scenario for disaster is vital, and the wrong decision might have terrible results. This part shows how variables are affected by changing the specific parameter, and then some explanations are written.

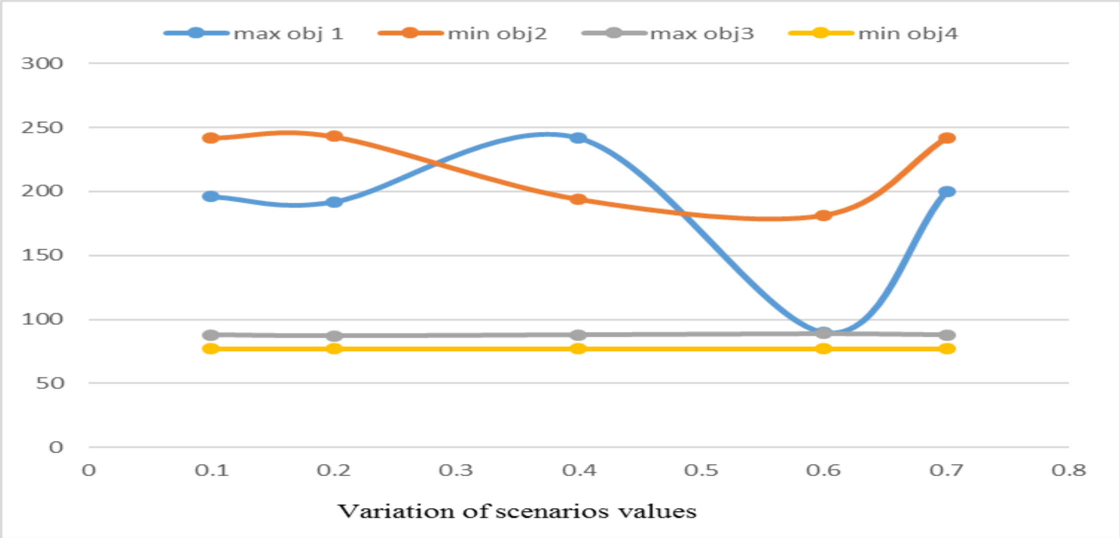

Fig. 10. Scenarios sensitivity

At Fig. 11, the capacity of distributions is raised. Number ‘0’ shows the initial result (initial capacity) and after that number ‘3’ means that every distribution's capacities are added 3 units and so on. According to Fig. 11, Objective number 4 is independent of the capacity of distributions, so its results have not changed. The exact solver minimizes the second objective (response time), but the results face a challenge which does not permission first objective satisfying completely, due to capacity of distributions which are selected for transferring relief items are limited, and demand at disaster areas are not satisfied, for meeting the first objective, the solver must choose other ways which have more capacity.

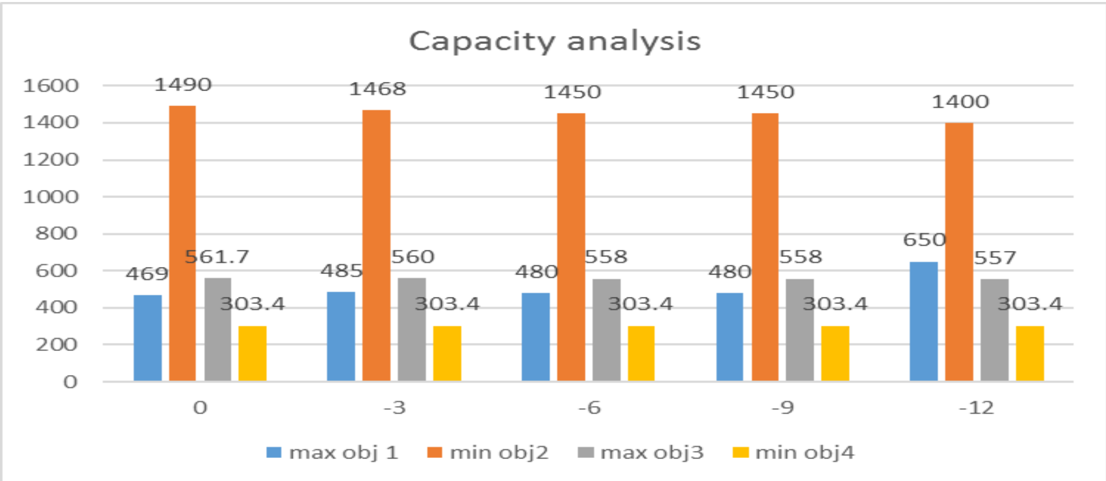

Fig. 11. Objectives analyses

Now one especial challenge is determined. This challenge is between objectives 1 and 2. Currently, one taxing parameter will be evaluated (Distance between a potential distribution and disaster point). In this part, the distance between possible distributions and disaster points that are not selected for transferring relief items is decreased. For satisfying object 1, the solver changes the strategy while the solver ignores the distributions' capacity, which causes objective 2's result to become worse than before.

According to Fig. 12, it is evident that by reducing the route's distance, which is not used, objective 2 may be decreased since it is possible new routes are selected. In this problem, new routes are chosen, but the capacity of distributions that are used in the new approach is less than distributions that are used in the old one, so objective one becomes worse. The third objective's results, like the previous section, do not have valuable analysis since it relates to determined parameters.

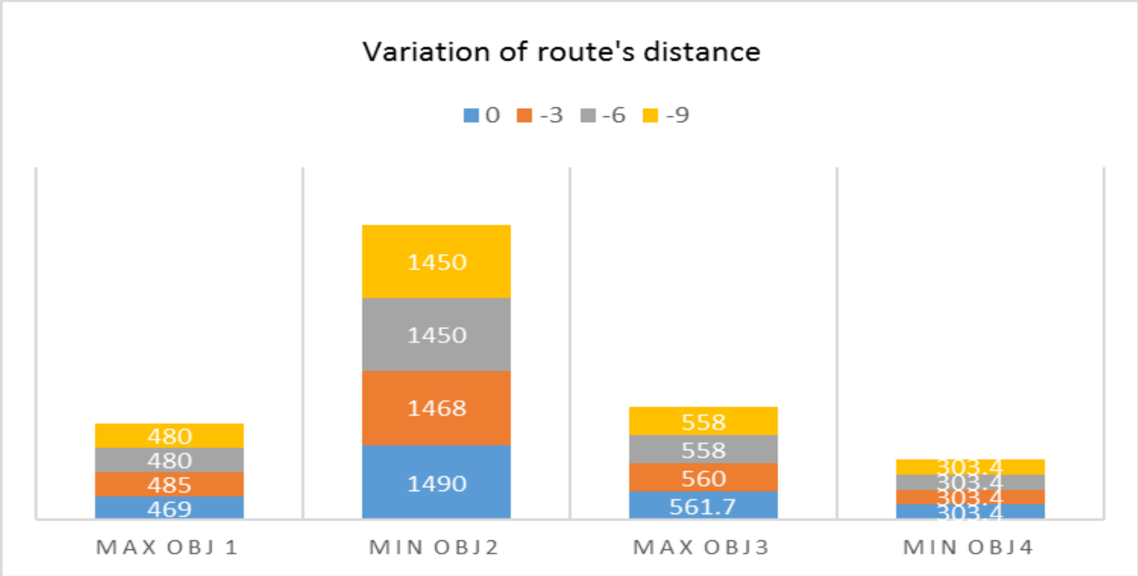

Fig. 12. Objectives analyses

Three important results are obtained from the above analyses. Firstly, the probabilities 'role is determined (how it can affect objectives, by allocating priority). The second result is determined that distributions' capacity has a prominent role in the humanitarian relief supply chain. If distribution capacities do not have ample area for transferring relief items, the first objective (satisfying demand), will not be satisfied properly. The third result has taxing consequences like the second result. Therefore, these results prove that wrong information causes the manager to choose the wrong strategy and shows the importance of the first stage. The first and second objective do not contrast with each other when distributions have enough area, and they contrast with each other when distributions have limited capacity.

Discussion and managerial insight

The humanitarian relief supply chain manager wants to reduce casualty in the shortest time with high quality. After this aim tries to transfer different items to satisfy demands at disaster points; therefore, efficient models can help managers select the best approach. The model, which is explained in the above sections, does its best to present an efficient strategy for satisfying objectives to the extent possible.

Some features of this model are mentioned in the rest of the paper. Unlike Noham and Tzur [1], this paper determines how initial data or parameters are obtained by drones and motorcycles sent for monitoring roads. The supply chain's manager sends these facilities after the disaster from potential distributions to disaster points. Then they collect information that is used in the next stages. The central manager evaluates collected information; according to their facilities and priorities, they determine the supply chain's approach. This paper considers the repairing stage which helps operations make safer while Noham and Tzur [1] did not consider this stage. Oruc and Kara [2] paid particular attention to monitoring the roads. It did not consider the rest of the operation, including repairing roads and satisfying demands, while this paper pays special attention to this part of the procedure. Vahdani et al. [3] did not consider monitoring and collecting information like this paper. They used information given this paper shows how this information is obtained or, in other words, this paper finds the collecting information stage.

The above reasons, which are mentioned, prove that this paper presents different results for different stages that can help the humanitarian relief supply chain manager. The monitoring result determines the best strategy for the first stage, repairing result uses for allocation groups to roads that are not appropriate for usage, and final stage results are used for satisfying demands. Manager's approach has a crucial role in this supply chain. The manager selects each objective's priority and determines the strategy of the supply chain for satisfying all objectives that are considered. In different situations, the manager decides how the supply chain tackles problems, and the manager selects the final decision.

Conclusion

This study presents a humanitarian relief supply chain model and considers repair groups, reliability of route, and monitoring operation before distributing relief items in different stages. This study shows how information is obtained, how repair groups are sent to increase the reliability of the route, and how humanitarian operations can send and allocate relief items to demand points. The results prove that all objectives are not satisfied, even all of the objectives have equal priority, so this is a taxing challenge for the humanitarian supply chain. For considering different approaches, unequal weight is a good method. It is a tradeoff between time and satisfying demand. This method cannot satisfy all demands like the previous method (equal priority), but the manager of the supply chain can choose the appropriate method for humanitarian operation. In different situations, different approaches are selected and the final decision is determined by the manager. This fact proves the importance of the management approach.

As the results show, the probability of scenarios can affect objectives, as each scenario has a different result and when the probability of each scenario becomes more or less, the object results become more and less, too. After that importance of distribution's capacities and route's distance between distributions and demand points are determined. The first and second objective approaches cause results to change, by the transformation of distribution's capacity and route's distance between distributions and demand points parameters. Finally, the manager decides the priority of these approaches. All in all, this study tries for evaluating the humanitarian supply chain with different approaches, and explain the results which are obtained from exact and metaheuristic solvers.

Future research for this paper can be done at different stages, which are explained at problem definition. At the first stage, the number of motorcycles and drones can be considered less than all the number of routes between distributions and demand points, with this approach motorcycles or drones might monitor different routes. In the third stage, all number of repair groups can be considered less than the number of routes that are selected for transferring relief items between distributions and demand points. At the final stage, different vehicles with different capacities and costs can be considered, and one objective about cost will be added.

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Appendix A

Initial parameters of small-scale test problem are presented:

Table A.1. Demand at disaster areas by considering scenarios at small scale

	1	2	3
S1	25	25	25
S2	20	25	30

Table A.2. Distance between warehouses and distributions at small scale

	c	d	e
A	11	1	11
B	1	1	2

Table A.3. Distance between distributions and disaster areas at small scale

	1	2	3
c	11	12	11
d	2	1	1
e	3	13	12

Table A.4. Reliability of route between distributions and disaster areas at small scale

	1	2	3
c	0.3	0.5	0.5
d	0.4	0.9	0.5
e	0.2	0.7	0.8

Table A.5. Repairing time route between distributions and disaster areas at small scale

	1	2	3
c	1	2	5
d	1	1	4
e	3	3	3

Table A.6. Monitoring time of routes by motorcycles and drones at small scale

	m 1	m 2	m 3	m 4	m 5	d 1	d 2	d 3	d 3
c.1	10	10	10	10	10	7	7	7	7
c.2	12	12	12	12	12	7	7	7	7
c.3	10	10	10	10	10	8	8	8	8
d.1	9	9	9	9	9	10	10	10	10
d.2	8	8	8	8	8	7	7	7	7
d.3	10	10	10	10	10	4	11	11	11
e.1	11	11	11	11	11	10	10	10	10
e.2	9	9	9	9	9	8	8	8	8
e.3	9	9	9	9	9	7	7	7	7

Appendix B

In this section medium-scale test problem's parameters are determined.

Table B.1. Demand at disaster areas by considering scenarios at medium scale

	1	2	3	4	5	6	7	8
S1	25	25	25	25	25	25	25	25
S2	20	25	30	20	25	30	25	25

Table B.2. Distance between warehouses and distributions at medium scale

	c	d	e	f
A	11	1	11	1
B	1	1	2	3

Table B.3. Distance between distributions and disaster areas at medium scale

	1	2	3	4	5	6	7	8
c	11	12	11	5	8	3	2	5
d	2	1	1	2	3	5	12	3
e	3	13	12	6	6	6	10	8
f	3	2	4	5	12	11	4	2

Table B.4. Reliability of route between distributions and disaster areas at medium scale

	1	2	3	4	5	6	7	8
c	0.3	0.5	0.5	0.4	0.7	0.4	0.7	0.8
d	0.4	0.9	0.5	0.4	0.5	0.9	0.4	0.2
e	0.2	0.7	0.8	0.9	0.8	0.3	0.1	0.2
f	0.2	0.9	0.5	0.7	0.7	0.3	0.1	0.7

Table B.5. Repairing time route between distributions and disaster areas at medium scale

	1	2	3	4	5	6	7	8
c	3	3	3	3	3	3	3	3
d	3	4	3	3	3	3	3	3
e	4	3	2	2	2	2	2	2
F	4	3	2	1	4	4	3	3

Table B.6. Monitoring time of routes by motorcycles and drones at medium scale

	m1- m20	d1- d12
c.1	3	2
c.2	4	1
c.3	3	2
c.4	2	3
c.5	4	4
c.6	8	3
c.7	9	4
c.8	4	5
d.1	3	3
d.2	2	1
d.3	3	4
d.4	3	5
d.5	7	5
d.6	8	3
d.7	2	1
d.8	2	9
e.1	4	3

Table B.6. Monitoring time of routes by motorcycles and drones at medium scale

	m1- m20	d1- d12
e.2	2	2
e.3	2	1
e.4	4	4
e.5	5	4
e.6	6	4
e.7	7	6
e.8	8	2
f.1	2	3
f.2	2	3
f.3	3	4
f.4	3	4
f.5	4	5
f.6	4	5
f.7	5	6
f.8	5	6

Appendix C

In this section, some parameters which have the obvious affect the results, are changed, and with this approach, validation of the model is proved (Model validation).

It is obvious that if all of the monitoring times are multiplied twice at the small scale, objective 4 will increase (old result *2), and with different times of multiplying that answer can change, so for validation of this theory, some examples are shown. The small scale's result of objective 4 is evaluated in Fig. C.1.

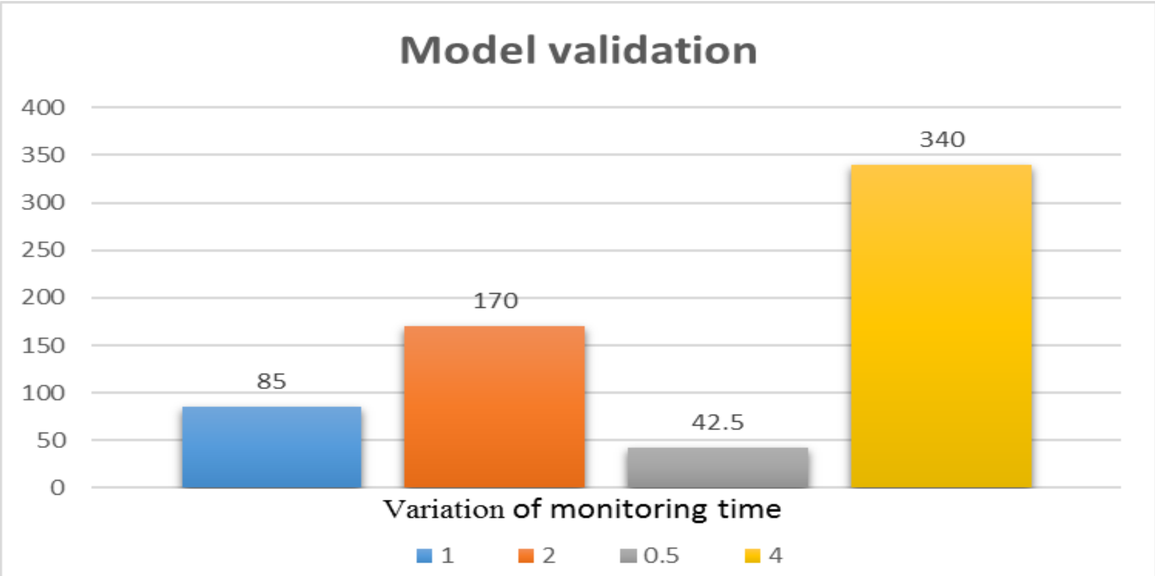

Fig. C.1. Model validation diagrams

According to Fig. C.1, number 1 shows that every monitoring time is multiplied one time, and number 2 shows that every monitoring times and so on.

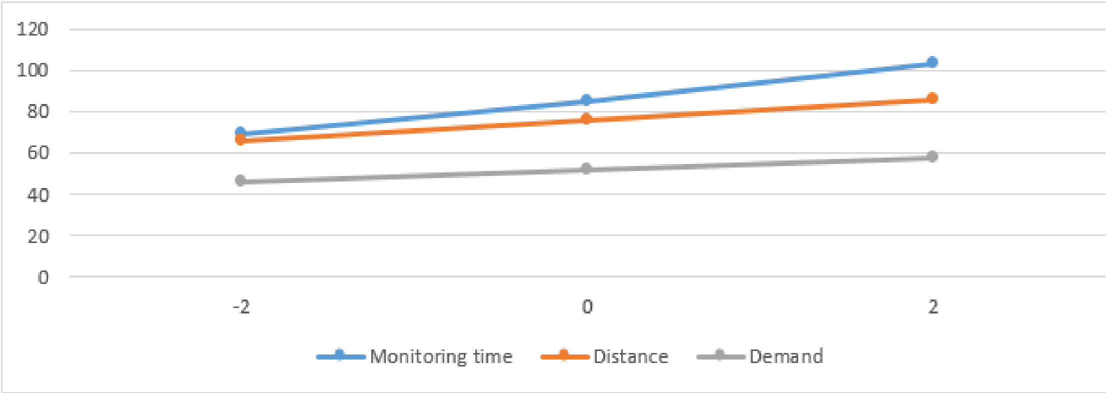

Fig. C.2. Model validation diagrams

It is clear that if all of the monitoring times are added 2, objective 4 will increase (old result + (number of potential distributions*number of disaster points) *2). The small scale's result of objective 4 is 85, after adding 2 units to each monitoring time, the result is changed to 103= (85+ (3*3) *2), so the validation of this part is shown. For the next evaluating, all of the distances between warehouses and distributions and then the distance between distributions and demand points are added 2 units, it is clear objective 2 is increased (old result + (number of the selected road for transferring relief items*2). The small scale's result of objective 2 is 76, after adding 2 units to each distance, the result is changed to 86= (76+ (5*2)). Now for testing other approaches, all of the demands are reduced 2 unites, and it is obvious that objective 1 is decreased (old result – (number of disaster points*2)). The new result is changed to 45.4= (51.4-(3*2)). All of these analyses are shown in Fig. C.2.

Appendix D

The hypothesis about equality of each objective's output which is achieved by the GAMS and grasshopper optimization algorithm is assessed, in this section. Moreover, for this evaluating, one sample is considered for each objective, whose size is 9. Then Minitab software is used for normal probability plots which are determined by metaheuristic algorithm's data. After previous steps, one efficient test whose name is Kolmogorov Smirinove is exercised to evaluate the normality. These test results are shown in Figs. D.1, D.2 and D.3. By considering these test results, P-values, which are obtained, are more than 0.05. So according to [30], the hypothesis tests (shown below) can be used for the population which does not have specific variance.

First objective hypothesis test

$$\begin{cases} H_0: Z_1 = 187 \\ H_1: Z_1 < 187 \end{cases} \tag{D.1}$$

The below equation is used for calculating static:

$$t_0 = \frac{187-\bar{Z}_1}{S_1/\sqrt{9}} \tag{D.2}$$

Moreover, $s1$ is determined by the below equation:

$$S_1=\sqrt{\frac{\sum_{i=1}^{9}(Z_1-\bar{Z}_1)^2}{8}} \tag{D.3}$$

$\overline{z1}$ and $s1$ are determined in Fig. D.1. The acceptable region is$(t_{\propto,8}, +\infty)$. For (α=0.005), acceptable region is (3.355 , +∞). According to Fig. D.1's data,$t0 = 3.81$, so the above hypothesis is accepted in a specific level of (0.005) and we can trust to GOA's results since they have acceptable differences with GAMS's results.

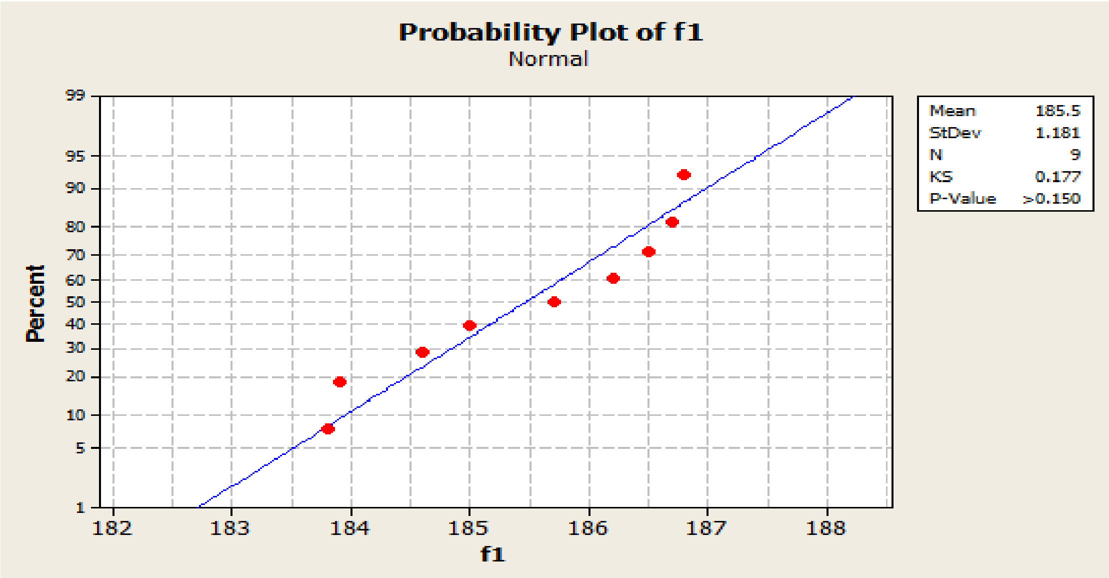

Fig. D.1. First objective normal probability test

Second objective hypothesis test

$$\begin{cases} H_0: Z_2=244 \\ H_1: Z_2>244 \end{cases} \tag{D.4}$$

The below equation is used for calculating static:

$$t_0=\frac{\bar{Z}_2-244}{S_2/\sqrt{9}} \tag{D.5}$$

Moreover, $s2$ is determined by the below equation:

$$S_2=\sqrt{\frac{\sum_{i=1}^{9}(Z_2-\bar{Z}_2)^2}{8}} \tag{D.6}$$

$\overline{z2}$ and $s2$ are determined in Fig. D.2 The acceptable region is$(-\infty , t_{\propto,8})$. For (α=0.005), acceptable region is (-∞ ,3.355). According to Fig. D.2's data,$t0 = 3.19$, so the above hypothesis is accepted in a specific level of (0.005) and we can trust to GOA's results since they have acceptable differences with GAMS's results.

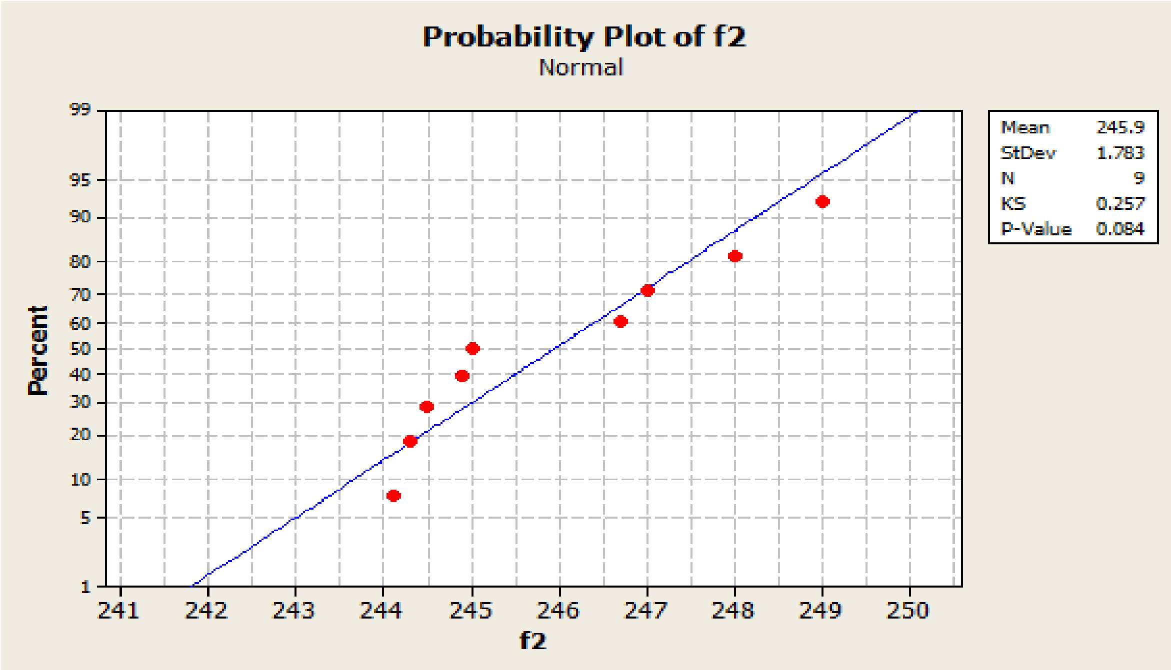

Fig. D.2. Second objective normal probability test

Third objective hypothesis test

$$\begin{cases} H_0: Z_3 = 88 \\ H_1: Z_3 < 88 \end{cases} \quad \text{(D.7)}$$

The below equation is used for calculating static:

$$t_0 = \frac{88 - \bar{Z}_3}{S_3 / \sqrt{9}} \quad \text{(D.8)}$$

Moreover, $s3$ is determined by the below equation:

$$S_3 = \sqrt{\frac{\sum_{i=1}^{9} (Z_3 - \bar{Z}_3)^2}{8}} \quad \text{(D.9)}$$

$\overline{z3}$ and $s3$ are determined in Fig. D.3. The acceptable region is $(t_{\propto,8}\ , +\infty)$. For ($\alpha$=0.005), acceptable region is (3.355, $+\infty$). According to Fig. D.3's data, $t0 = 3.39$, so the above hypothesis is accepted in a specific level of (0.005) and we can trust to GOA's results since they have acceptable differences with GAMS's results.

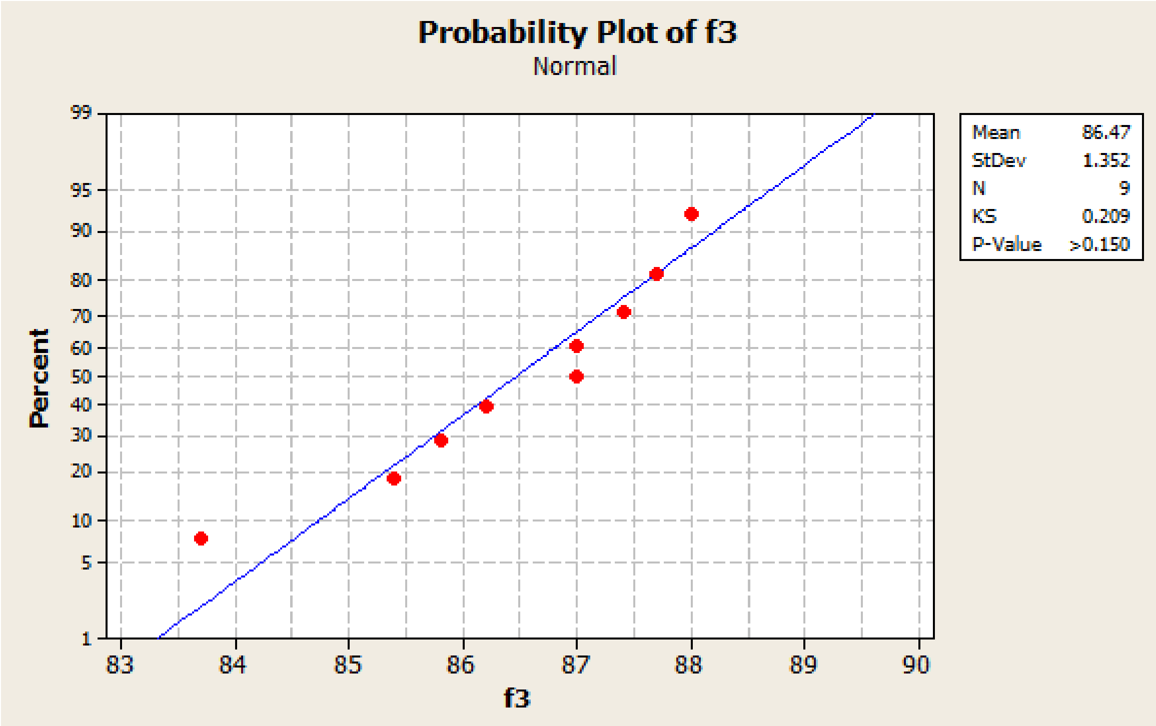

Fig. D.3. Third objective normal probability test

Fourth objective hypothesis test

$$\begin{cases} H_0 : Z_4 = 77 \\ H_1 : Z_4 > 77 \end{cases} \qquad \text{(D.10)}$$

The below equation is used for calculating static:

$$t_0 = \frac{\bar{Z}_4 - 77}{S_4 / \sqrt{9}} \qquad \text{(D.11)}$$

Moreover, $s4$ is determined by the below equation:

(D.12)

$\overline{z4}$ and $s4$ are determined in Fig. D.4. The acceptable region is $(-\infty\ , t_{\propto,8}\ )$. For (α=0.005), acceptable region is (-∞ ,3.355). According to Fig. D.4's data,$t0 = 3.18$, so the above hypothesis is accepted in a specific level of (0.005) and we can trust to GOA's results since they have acceptable differences with GAMS's results.

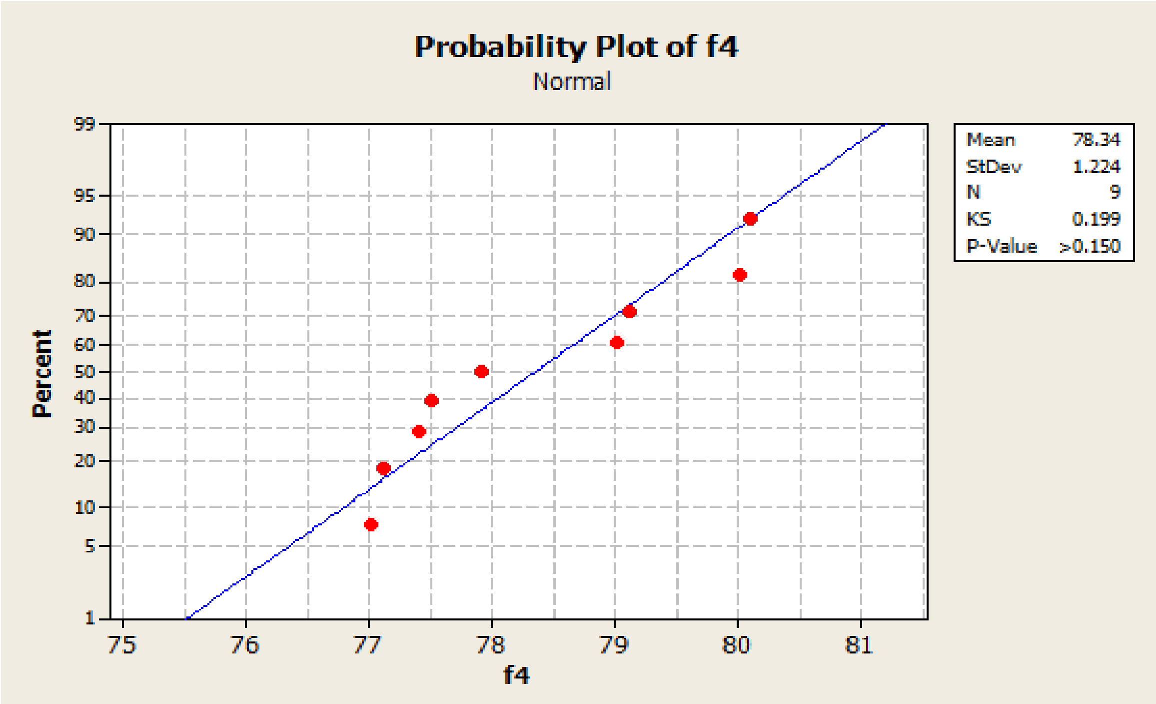

Fig. D.4. Fourth objective normal probability test

Appendix E

Fig. E.1 illustrates the solving time of Gams and GOA in different sizes of problems. According to Fig. E.1, the solving time of Gams has been soared by increasing the size of problems exponentially. Finally, it is shown Gams cannot solve big-scale problems, while GOA could solve them in appropriate solving time with a 4.5 % gap.

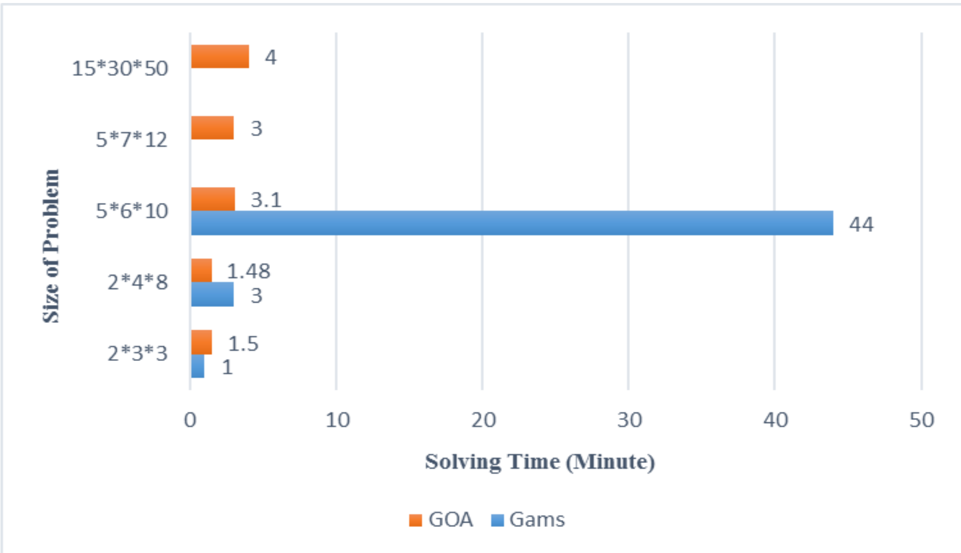

Fig. E.1. Comparison of solving time of Gams and GOA

The label of 2*3*3 means a problem including 2 warehouses, 3 distribution candidates, and 3 demand points. Also, solving time of the problems is shown on a minute scale. For example, the problem with 5*6*10 size is solved in 44 minutes by GAMS and is solved by GOA in 3.1 minutes.