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Multi-objective routing and scheduling for relief distribution with split delivery in post-disaster response

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Abstract

Following the occurrence of unexpected events and natural disasters, a highly important relief operation is the transferring of relief commodities from the distribution centers (DCs) to shelters. In this paper, a three-level network consisting of depot of vehicles, distribution centers,and shelters has been considered for routing and scheduling of relief vehicles through introducing a multi-objective model. The first objective function represents the total arrival time of vehicles to DCs and shelters. The second objective function illustrates the number of vehicles used. We use the TH method to deal with the multi-objective problem. During the relief commodities distribution, issues such as the feasibility of getting service from each distribution center with multiple vehicles and heterogeneous fleet of vehicles has been regarded. In order to solve the proposed model and represent its efficiency, we select the fourth region of Tehran city as a case study; run the model on it, and present solution results.

Keywords: Disaster Management, Multi-objective optimization, Routing, Scheduling

1- Introduction

The occurrence of natural and man-made disasters such as flood, earthquake, thunderstorm, etc. would cause drastic social and economic damages, as well as the displacement and even the death of thousands of people. Accordingly, in order to lower the casualties and economic losses in these disasters, certain relief operations should be considered(Najafi et al., 2013). These operations include debris collection for opening relief routes, rescue operations, transportation of the injured people to medical centers, transportation of evacuees to the shelters, and distribution of relief commodities.

The key decisions that can be mentioned in the response phase to disasters include scheduling, routing, allocation, location, and inventory. However, the literature has not noticeably covered the issues of routing and scheduling in the field of distributingcommodities in the response phase of a disaster while the simultaneous analysis of these decisions is recognized as a new domain of study. In the following, conducted studies in this field are discussed.

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Bish (2011) introduced a single-objective deterministic model of routing and allocating for transporting evacuees from affected areas to the shelters for the purpose of realizing service to each affected area with several vehicles. Abdelgawad and Abdulhai (2011) offered a single-objective deterministic model of routing, scheduling, and allocation for transporting evacuees from the affected areas to shelters; they have considered the possibility of servicing to any affected area with several vehicles. Nolz *et al*. (2011) represented a multi-objective deterministic model for routing the relief commodities distribution from a relief center to the affected areas which considered the service to each affected area with only one vehicle. Hamedi *et al.*(2012) introduced a multi-objective deterministic model for routing and scheduling the relief commodities distribution from relief centers to the shelters;they have considered the possibility of servicing to any shelter with several vehicles. Wohlgemuth *et al.*(2012) proposed a single-objective deterministic model for routing and scheduling the distribution of relief commodities from a relief center to affected areas, considering only one vehicle for serving each affected area. Wex *et al.*(2012) represented a single-objective uncertain model for routing rescue operations, in which only one rescue unit served each affected area. Gan *et al.*(2013) introduced a single-objective uncertain model for routing and scheduling the distribution of relief commodities to the affected areas, considering utility function and serving each affected area with only one vehicle. Lee *et al.*(2013b) represented a single-objective deterministic model for scheduling medical operations in hospitals along with introducing the concepts of distribution centers and dividing sources into two categories of renewable and non-renewable. They considered infinite capacity for distribution centers, and assumed each hospital to be served solely through one distribution center. Lee *et al.*(2013a) proposed a single-objective deterministic model for scheduling distribution of medical supplies to the hospitals along with introducing the concept of distribution centers. They also considered finite capacity for distribution centers, and assumed each hospital to be served through only one distribution center. Pramudita *et al.*(2014) introduced a single-objective dynamic model for routing, locating, and allocating debris collection operations from affected areas to the depots, in which serving each affected area was performed by only one vehicle. Ozdamar *et al.*(2014) introduced a multi-objective dynamic model for routing and scheduling debris collection operations from affected areas, considering a vehicle for serving each affected area. Wex *et al.*(2014) introduced a single-objective deterministic model for routing rescue operations in affected areas, considering a rescue unit to serve each affected area. Rath and Gutjahr (2014) suggested a multi-objective deterministic model for routing and locating the distribution of relief commodities from relief centers to affected areas, using a vehicle for serving each affected area. Caunhye *et al.*(2015) proposed a single-objective uncertain model for routing and locating the distribution of relief commodities from relief centers to affected areas, in which only one vehicle served an affected area. Talarico *et al.*(2015) introduced a multi-objective uncertain model for routing and scheduling the transportation of injured people from the affected areas to the hospitals, considering a vehicle for serving each affected area. Gan *et al.* (2015) proposed a single-objective deterministic model for routing and scheduling distribution of relief commodities from a relief center to affected areas using utility function, in which serving each affected area was performed with a vehicle. Considering earlier researches, the gaps in the literature can be summarized as follows:

- Most routing and scheduling papers are two-level that are included depot and affected areas.
- In routing papers, little attention has been paid to such features as the possibility of serving each node by several vehicles, open routes, and a heterogeneous fleet of vehicles.
- In most papers, the capacities of such facilities as shelters, hospitals and so on have been assumed unlimited.
- Most routing and scheduling papers are single-objective.

The contributions of this paper are as follows:

- Introducing a new mathematical model for routing and scheduling of relief vehicles for transferringcommodities from DCs to the shelters.
- Feasibility of getting service from each DCwith several relief vehicles (split delivery).
- Considering heterogeneous vehicles with limited capacity.

- Applying the model to a real-world case study of disaster relief.
- Presenting a multi-objective model and solving it with TH method.

In the following, the considered network is primarily described. In section 3, the mathematical modeling of the problem is explicated in detail. The solution procedure is introduced and explained in section 4. In section 5, results of the model solution on real-world data are reported. The conclusions and suggestions for future studies are represented in the final section.

2- Problem description

Transferring of relief commodities from DCs to the shelters is one of the most critical operations in the response phase to a disaster.

As it can be observed in Figure1, any relief vehicle such as a truck or trailer, would start its operation from the depot where it is located, in case of being dispatched, and subsequently, it will select the best route for transferring the commodities from the distribution centers to one of the shelters according to the its own capacity and the demand of the shelters.

Given the introduced network, the number and location of distribution centers and shelters are known. The vehicles considered for the relief operations are heterogeneous with limited capacity. Moreover, the depot where each vehicle is located has been determined, and in case of dispatching a vehicle, the location for end of the operation is unknown and only to one of the shelters.

In the distribution operation, there is the feasibility of getting service from each DCwith several relief vehicles, for the purpose of obtaining best performance. The travel times between all the nods of the network are symmetric and follow triangular inequality.

By proposing a new mathematical model, simultaneous routing and scheduling of relief vehicles will be realized, with the purpose of lowering the total arrival time of relief vehicles to DCs and shelters and the number of vehicles used.

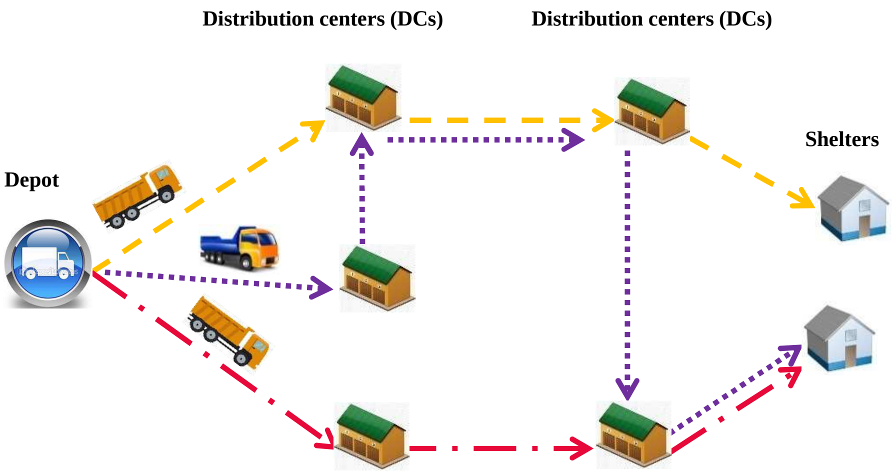

Fig.1. relief commodities supply network

3- MILP formulation

Let us start with a description of the sets, the parameters, decision variables, and the proposed mathematical model.

3-1- Model sets and indexes

E	Set of distribution centers
S	Set of shelters

V	Set of available vehicles fleet indexed by $v \in V$
D	Vehicles depot
N	Set of all nodes (assembly of S , E and D indexed by $i, j \in N$)

3-2- Model parameters

c_{ij}	Transportation time from node $i \in N$ to node $j \in N$
d_i	Demand of the shelter $i \in S$
s_i	Supply of distribution center $i \in E$
Cap_v	Capacity of vehicle $v \in V$
Dt_i	Servicing time at node $i \in E \bigcup S$
M_{big}	A large number

3-3- Model variables

X_{vij}	Equals 1 if vehicle $v \in V$ moves from node $i \in N$ to node $j \in N$; otherwise it is zero
Y_{vi}	Equals 1 if vehicle $v \in V$ is allocated to node $i \in E \bigcup S$; otherwise it is zero
Z_v	Equals 1 if vehicle $v \in V$ is dispatched; otherwise it is zero
Q_{vi}	Number of commodities loaded by vehicle $v \in V$ from distribution center $i \in E$ or number of commodities delivered at shelter $i \in S$ by vehicle $v \in V$
T_{vi}	The time vehicle $v \in V$ reaches node $i \in N$

3-4- The proposed mathematical model

The explained mathematical programming model is as follows:

Objective functions

$$Min \sum_{v \in V} \sum_{i \in E \bigcup S} T_{vi} \tag{1}$$

$$Min \sum_{v \in V} Z_v \tag{2}$$

Routing and flow balance constraints

$$\sum_{j \in E} \sum_{i \in D} X_{vij} = Z_v \qquad \forall v \in V \tag{3}$$

$$\sum_{i \in D \bigcup E, i \neq j} X_{vij} = \sum_{i \in E \bigcup S, i \neq j} X_{vji} \qquad \forall j \in E, \forall v \in V \tag{4}$$

$$\sum_{j \in E \bigcup D, j \neq i} X_{vji} = Y_{vi} \qquad \forall i \in E, \forall v \in V \qquad (5)$$

$$Cap_v Y_{vi} \geq Q_{vi} \qquad \forall i \in E \bigcup S, \forall v \in V \qquad (6)$$

$$\sum_{j \in E \bigcup S, j \neq i} X_{vji} = Y_{vi} \qquad \forall i \in S, \forall v \in V \qquad (7)$$

$$\sum_{v \in V} Q_{vi} = d_i \qquad \forall i \in S \qquad (8)$$

Number and capacity of relief vehicles and shelters constraints

$$\sum_{v \in V} Q_{vi} \leq s_i \qquad \forall i \in E \qquad (9)$$

$$\sum_{i \in E} Q_{vi} \leq Cap_v Z_v \qquad \forall v \in V \qquad (10)$$

$$\sum_{i \in S} Q_{vi} = \sum_{i \in E} Q_{vi} \qquad \forall v \in V \qquad (11)$$

$$\sum_{v \in V} Z_v \leq V \qquad (12)$$

Scheduling constraints

$$T_{vi} = 0 \qquad \forall i \in D, \forall v \in V \qquad (13)$$

$$\left(T_{vi} + Dt_i + c_{ij}\right) - M_{big}\left(1 - X_{vij}\right) \leq T_{vj} \qquad \forall j \in E, \forall v \in V, \forall i \in D \bigcup E, i \neq j \qquad (14)$$

$$\left(T_{vi} + Dt_i + c_{ij}\right) - M_{big}\left(1 - X_{vij}\right) \leq T_{vj} \qquad \forall j \in S, \forall v \in V, \forall i \in E \bigcup S, i \neq j \qquad (15)$$

Domain constraints

$$X_{vij} \in \{0,1\} \qquad \forall i \in N, \forall j \in N, \forall v \in V \qquad (16)$$

$$Y_{vi} \in \{0,1\} \qquad \forall i \in E \bigcup S, \forall v \in V \qquad (17)$$

$$Z_v \in \{0,1\} \qquad \forall v \in V \qquad (18)$$

$$Q_{vi} \geq 0 \qquad \forall i \in E \bigcup S, \forall v \in V \qquad (19)$$

$$T_{vi} \geq 0 \qquad \forall i \in N, \forall v \in V \qquad (20)$$

The objective function (1) represents the total arrival time of vehicles to distribution centers and shelters. The objective function (2) minimizesthe number of vehicles used .The constraint (3) indicates that in case of dispatching a vehicle, that specific vehicle moves from the depot toward one of the distribution centers. The constraint (4) is the constraint of flow balance within the DCs. Constraint (5) illustratesthat when a vehicle is allocated to a distribution center, before this area, there is only one other DC or the vehicle's depot. Constraint (6) represents the relation between two variables of Q_{vi} and Y_{vi} in each of the distribution centers and shelters. Constraint (7) indicates that when a vehicle is allocated to a shelter, before this shelter, there is only one DC.Constraint (8) ensures that demands in shelters are fulfilled.Constraint (9) indicates the maximum supply of eachdistribution center. Constraint (10) expresses the maximum capacity of each vehicle. Constraint (11) indicates that the number of commodities a vehicle loads at different DCs is equal to that it unloads in a shelter.Constraint (12) represents the maximum number of available vehicles. Constraint (13) sets the initial value of zero for the time parameter when each vehicle leaves its depot. Constraints (14) and (15) expresses the arrival time of each vehicle to each distribution center and each shelter, respectively. Constraints (16) to (20) express the type of variables.

4- Solution procedure

The fuzzy programming methods are useful for finding an efficient solution to multi-objective problems. Torabi and Hassini(2008) proposed an interactive fuzzy approach to solve the multi-objective problems. The TH solution procedure is summarized in following four steps:

Step 1: Determine the positive ideal solution (PIS) and negative ideal solution (NIS) for each objective function by solving the model as follows:

To increase the procedure speed, obtain an approximate positive ideal solution for each objective function. For this purpose optimize each objective function independently. The negative ideal solution can be estimated using the positive ideal solutions (21).

$$Z_o^{NIS} = \max_{k=1,2,..,K} \{Z_o(v_k^*)\} \qquad \forall o \tag{21}$$

Where $Z_o(v_o^*)$ is the corresponding value of *oth* objective function and v_o^* is the decision vector related to the PIS of *oth* objective function.

Step 2: Create a linear membership function for each objective function as follows (22):

$$\mu_o(x) = \begin{cases} 1 & Z_o < Z_o^{PIS} \\ \dfrac{Z_i^{NIS} - Z_o}{Z_o^{NIS} - Z_o^{PIS}} & Z_o^{NIS} \le Z_o \le Z_o^{PIS} \\ 0 & Z_o > Z_o^{NIS} \end{cases} \tag{22}$$

Where $\mu_o(x)$ is the satisfaction degree of objective function 'o'.

Step 3: Convert the multi-objective model into an equivalent single-objective model using the following crisp formulation (23):

$$Max\ \lambda(\mathrm{v}) = \gamma\lambda_0 + (1-\gamma)\sum_o \theta_o \mu_o(v)$$

s.t.(23)

$$\lambda_0 \le \mu_o(v), \qquad o = 1, 2, ..., \mathrm{O}$$

$$v \in F(v)$$

$$\lambda_0 \quad and \quad \gamma \in [0,1]$$

$\mu_O(v)$ and λ_0 denote the satisfaction degree of *oth* objective function and the least satisfaction degree of objective functions respectively. θ_O implies the preference of the *oth* objective function and γ indicates the coefficient of compensation. The θ_O parameters should be determined such as $\sum_O \theta_O = 1$ and $\theta_O \geq 0$.

Step 4: solve the proposed crisp model (23). If the current efficient compromise solution is agreeable, stop. Otherwise, change the value of some controllable parameters such as β and γ, then go back to Step 1.

5- Case study

In this section, due to the novelty of aforementioned characteristics for the proposed model in the field of relief operation in response phase to a disaster, a case study along with its solution will be provided.

Tehran is divided into 22 regions among which region 4 is densely populated, and consists of 9 zones. Faults around this region include:

1) Shian and Kousar with lengths of 13 km.
2) Narmak, a secondary fault, with a length of 2.5 km.

In this paper, zones 1, 3 and 7 have been considered. The number of evacuees to be evacuated to shelters (based on the region's crisis management experts' polls) is shown in Table 1.

Table 1. Tehran region 4 zones centers and number of evacuees to be evacuated to shelters

Zones	Zones centers	Number of evacuees to be evacuated to shelters
1	Seif Street	575
3	HeraviStreet	2251
7	Hengam Street	634

Eshragh Cultural Center, Golshan Stadium, Azad University -North Tehran Branch-, and Arash Stadiumare set as shelters.In the process of relief commodities distribution, Ershad, Amir Kabir, and Hadaf schools have been considered as DCs and Hakimieh Crisis Shed has been introduced as the depot of vehicles. A maximum of 8 vehicles are available for transferring the commodities. Tables 2 and3 mention the required information for describing the problem.

Table 2. Information regarding the network nodes

Nodes	DCs capacity (commodity)	demand of shelters (commodity)	Servicing time (min)
Eshragh Cultural Center	-	1200	30
Golshan Stadium	-	750	30
Arash Stadium	-	800	30
Azad University	-	710	30
ErshadSchool	1160	-	30
Amir KabirSchool	1160	-	30
HadafSchool	1160	-	30

Table 3.capacities of relief vehicles

Vehicles	Capacity of each vehicle
1	1200
2	800
3	800
4	800
5	800
6	700
7	700
8	700

5-1-Solution results

The selected problem was solved using GAMS 23.0.2 software and CPLEX solver on a computer system of Intel Core i7 4702MQ 2.20GHz up to 3.20 GHz and 6GB RAMDDR3 under Windows 7. The solving time of this problem with GAMS software has been 900 seconds. After solving the problem using TH method, the obtained results were 336.4 minutes and 5 vehicles for the first and second objective functions, respectively.The obtained results are mentioned in Table 4 and schematically demonstrated in Fig.2.

As in Table4 and Fig.2, the route of each vehicle, number of commoditiesloaded up at each DC and unloaded at the related shelter, and the time each vehicle reaches a DC and the related shelter are represented. For instance, vehicle 1 has started its operation from depot; has taken 40commodities from Hadaf School, 7.3 minutes after the departure, has reached Ershad School after 42.2 minutes, loading 1160commoditiesfrom it, and finally, has unloaded 1200 commodities to Eshragh Cultural Centerafter 80.4 minutes.

Table 4. The obtained Results of the model

Vehicles	Route of each vehicle	Number of commodities vehicle loads at a DC and unloads at the related shelter	Arrival time of each vehicle (min)
1	Hakimieh Crisis Shed – HadafSchool - ErshadSchool –Eshragh Cultural Center	0-40-1160-1200	0-7.3-42.2-80.4
2	Hakimieh Crisis Shed – HadafSchool – Azad University	0-350-350	0-7.3-41.3
3	Hakimieh Crisis Shed – HadafSchool – Golshan Stadium	0-750-750	0-7.3-42
4	Hakimieh Crisis Shed – Amir KabirSchool - Azad University	0-360-360	0-11.5-42.5
5	Hakimieh Crisis Shed – Amir KabirSchool- Arash Stadium	0-800-800	0-11.5-43.1

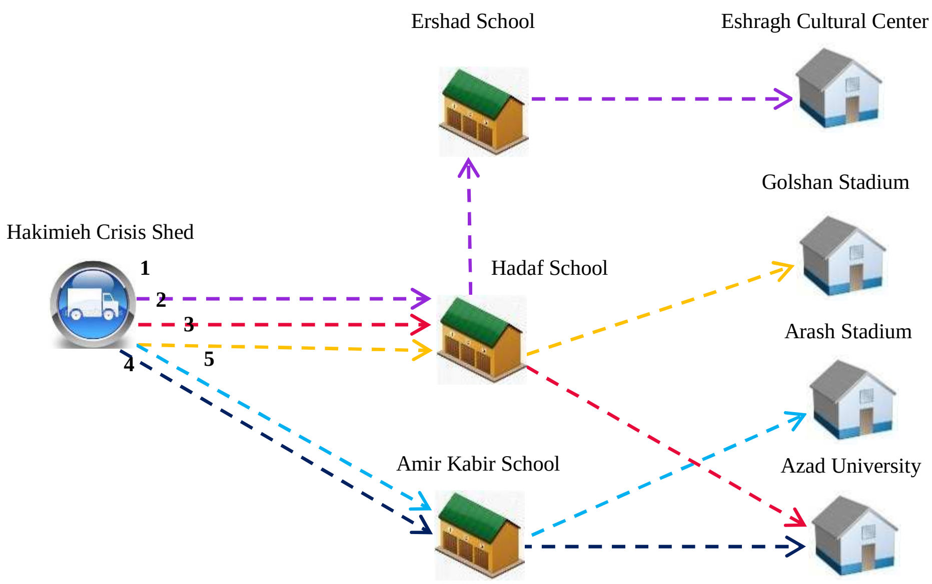

Fig. 2. The obtained Results of the modelschematically

5-2- Sensitivity analysis

In the following, two types of sensitivity analysis have been conducted for studying the influence of changing the supply of DCs. Subsequently, the results of these analyses on the total time of relief operations and the number of vehicles used have been represented.

Decreasing the time of relief operations in the response phase of a disaster is highly significant on minimizing the damages and losses. According to Fig.3, the maximum supply of DCs is one of the influential parameters on the duration of the abovementioned operation. As it can be observed, increasing the maximum supply of DCs from 1155 to 1160 commodities reduces the response time for 19.2 minutes; while increasing this number to 1200 commodities lowers the total arrival time of relief vehicle to distribution centers and shelters for 67.7 minutes.

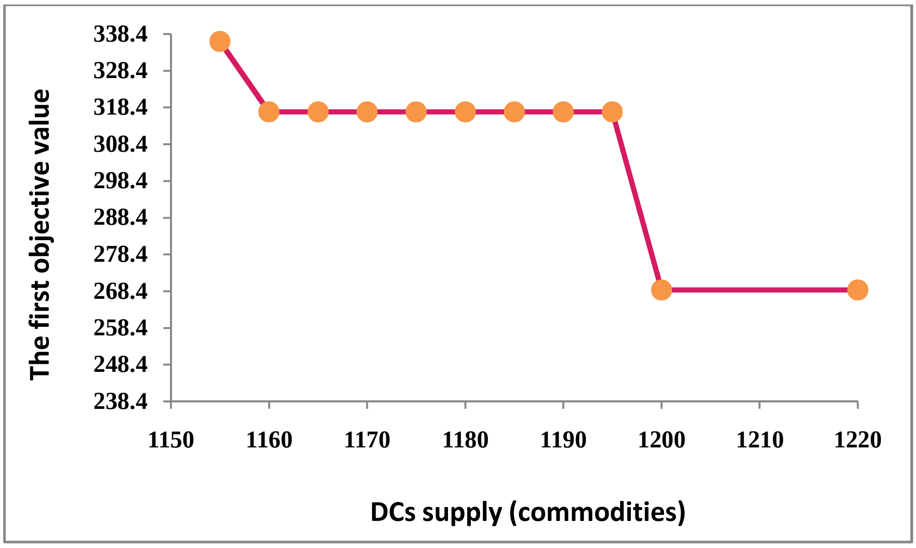

Fig.3. sensitivity analyses of the first objective with respect to the supply of DCs

The endeavor of decision makers in the field of disaster management is toward a more efficient utilization of facilities. As it can be noticed in Fig.4, increasing the supply of DCs from 1155 to 1160 commodities lowers the number of vehicles used by 1 vehicle. Moreover, a further increase of this supply to 1200 commodities would result in a 2-vehicle decrease.

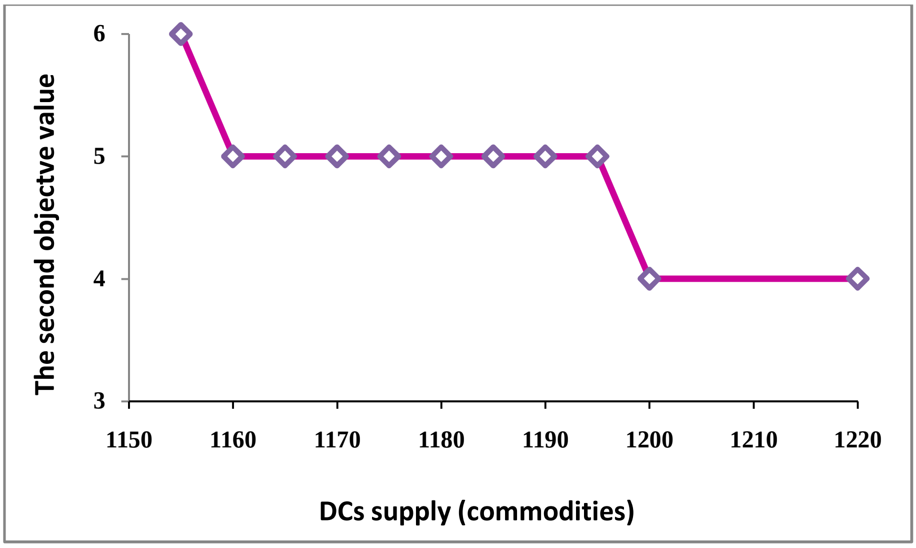

Fig.4. sensitivity analyses of the second objective with respect to the supply of DCs

6- Conclusion and future research

Upon the occurrence of disasters, particularly in the response phase, unplanned proceedings will be performed which might cause unexpected problems. However, through applying optimization actions such as those in Operation Research (OR), schedules and decision-making processes could be optimized and the damages due to the mismanagements would accordingly be reduced to a high extend. Given this fact, this paper introduces a multi-objective model for simultaneous routing and scheduling of relief vehicles for transferringcommodities in the response phase of a disaster. The novelty of this paper compared to previous literature is considering a three-level network consisting of depot of vehicles, distribution centers (DCs), and shelters. To make the problem closer to real conditions, existing constraints such as number and capacity of relief vehicles, and split delivery have been considered for a more efficient management of the disaster. Our model has introduced two objectives: (1) present the total arrival time of vehicles to DCs and shelters, and (2) explain the number of vehicles used. To solve this bi-objective problem, the TH approach has been used. In order to validate the introduced model, the model has been applied and solved for a case study.
For the future studies, following issues can be regarded:

1- Considering traffic and network disruption for transportation routes
2- Improvement of the current model for a multi-period condition
3- Using metaheuristic algorithms for solving large-scale models

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