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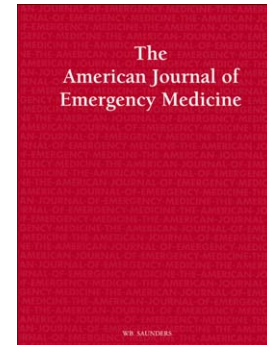
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## Integrated Locating of Helicopter Stations and Helipads for Wounded Transfer under Demand Location Uncertainty

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## Integrated Locating of Helicopter Stations and Helipads for Wounded Transfer under Demand Location Uncertainty

### *Abstract*

Health emergency medical service (HEMS) plays an important role in reducing injuries by providing advanced medical care in the shortest time and reducing the transfer time to advanced treatment centers. In the regions without ground relief coverage, it would be faster to transfer emergency patients to the hospital by a helicopter. In this paper, an integer nonlinear programming model is presented for the integrated locating of helicopter stations and helipads by considering uncertainty in demand points. We assume three transfer modes: (1) direct transfer by an ambulance, (2) transfer by an ambulance to a helicopter station and then to the hospital by a helicopter, (3) transfer by an ambulance to a predetermined point and then to the hospital by a helicopter. We also assume that demands occur in a square-shaped area, in which each side follows a uniform distribution. It is also assumed that demands in an area decrease errors in the distances between each two cities. The purpose of this model is to minimize the transfer time from demand points to the hospital by considering different modes. The proposed model is examined in terms of validity and applicability in Lorestan Province and a sensitivity analysis is also conducted on the total allocated budget.

**Keywords:** Helicopter Emergency Medical Service, Emergency Medical Service, Transfer Point Location Problem, Uncertainty

## 1- Introduction

Helicopter emergency medical service (HEMS) was first used in 1944 when the beach guard helicopters transferred blood plasma from New York to survivors from a massive explosion in New Jersey. Twenty years later during Korea War, about 20,000 injured were transferred to hospitals by helicopters [1]. In Iran, HEMS was first used in 1981 to transfer trauma patients during Iran-Iraq War [2]. Injury and harm influence the performance of body and organs. Most of these injuries become serious without intervention, but quick and timely actions can help the wounded to survive. Emergency experts describe this time as "accident subsequent golden time", during which half of the deaths occur.

In the regions without ground relief coverage, locating helicopter stations makes it easier to transfer emergency patients to medical centers. Emergency helicopters can pass directly between two points, cover vaster area and also have more speed than ground ambulances. Thus, they can give better services to emergency injuries or the wounded with limited access to hospitals. Some points are geographically mountainous or have high population density that disturbs the helicopter landing process. So it seems critical to install helipads for the successful implement of HEMS [3].

HEMS usually acts as follows: first, an emergency unit like an ambulance is sent to the incident location. After evaluating the situation of injuries, a helicopter is requested to transfer the injured to the hospital if necessary. After that, the ambulance transfers the injured people to the helipad which is appropriate for helicopters for landing and taking-off. At the same time, a helicopter is sent out to the helipad from the helicopter station. Because of this complex structure, designing an efficient HEMS system requires more complicated decisions than the ground ambulance transfer system [3]. Generally, there are three assumed transfer modes as follows:

1. Transferring patients directly to the hospital by an ambulance from demand areas
2. Moving patients to the helicopter station by an ambulance and then transferring them to the hospital by a helicopter deployed at the station
3. Transferring patients to the helipad by an ambulance and then transferring them to the hospital by a helicopter

The purpose of this study is to find the optimal helicopter stations and helipad locations considering uncertainty in demand areas. The necessity of assuming demands in an area form, instead of single point, is to decrease computational errors occurring when the distance travelled between cities or facilities in the area is assumed as the distance between those areas' center points [4]. Subject to the uncertainty of incident points in the real world, in this paper, we assume that a demand occurs in a square demand area and its length and width follow a uniform

distribution. As we reviewed the most important studies in HEMS context, this paper is the first one which considers demand point in an area shaped type.

Generally, novelties of this paper compared to other works are as follows:

1. A new model for simultaneously locating helicopter stations and helipads for the transfer of the wounded
2. Ways of considering demands in a uniformly distributed area, instead of single demand points
3. Ways of considering rectilinear distance for ambulances and Euclidean distance for helicopter movement
4. Ways of considering budget constraints for the establishment of facilities
5. Implementing the model in Lorestan Province, Iran, as a real case study

The organization of this paper is as follows: first, we review the literature of HEMS and the transfer point problem. Then, we describe the problem and explain the possible modes and assumptions and also present the problem modeling. Afterwards, we represent a numerical example of the problem and perform sensitivity analysis on the parameter of assigned budget. In the next step, the model case study (Lorestan Province) is represented. Finally, the conclusion and future suggestions are made.

## 2- Literature review

Studies on emergency medical service (EMS) stations widely emerged in 1970s [5]. Based on the literature, most researchers have been focused on the establishment of EMS stations, especially ambulance location problem. A comprehensive study on this subject is in [6] and [7]. Helicopter location models have been less considered than ambulance location models. Hub-and-spoke models are most relevant to the transfer point problem and can be the basis of TPLP models. The aim of the hub location problem is to establish hub facilities and allocate demand nodes to hubs in order to route the path between origin and destination centers [8]. Goldman [9] proposed the first study in the area of hub location problem in the networks and reviewed the hub nodes optimizing features in Hakimi's work. O'Kelly [10] formulated the first known mathematical model of hub location by studying passenger airlines. To consider a comprehensive review in hub location problems, the literature is summarized in Alumur and Kara [11].

Berman et al. [12] defined the transfer point problem as follows: "the problem of selecting a location of a new facility which plays the role of a hub center and covers  $N$  demand points".

Although the transfer point location problem is in the category of hub location problems, it is different from this category in two main aspects. First, hub location problems are often studied on the network, but the transfer point location problem is

not limited to this topology. Second, in hub location problems, the demand exists between each pair of nodes and there is no backup facility, but in the transfer point problem, these facilities play a substantial role in the model [8]. For the first time, Berman et al. [13] discussed transfer point location problem (TPLP), the purpose of which is to determine the transfer point location by considering predetermined facility location and assuming that the demand points can be serviced by transfer point. Berman et al. [14] also studied facility and transfer point location problem (FTPLP) in another work, which aimed to determine the location of facilities and the transfer points under such conditions that the location of facilities and transfer points were not predetermined and each demand point could be serviced from facilities by a transfer point and a heuristic approach can also be presented to solve it. Berman et al. [15] also presented multiple location of transfer point (MLTP) problem with the purpose of determining the location of transfer points by assuming that locations of facilities and transfer points were predetermined and each demand point could be serviced from facilities by a transfer point. Sasaki et al. [16] extended the MLTP problem similar to the P-median problem and got the optimum values. They also presented a new model of FTLP problem and provided an enumeration-based approach to solve single facility problems. Berman and Drezner [17] studied P-median problem by considering uncertainty in a number of servers.

Also in the field of locating helicopter stations, the most important works are as follows: Schuurman et al. [18] developed an approach to assign an additional helicopter station so as to maximize the demand coverage of regions without a helicopter station. They implemented their model in a real case where two hospitals with helicopter medical services existed. In their analysis, five years of critical care data from British Columbia Trauma Registry along with population and travel time data were employed. Branas et al. [19] presented a model that could simultaneously determine optimum locations of trauma centers and helicopter stations. They also suggested a heuristic algorithm to solve their model and implemented their model in many regions in the United States [20]. Fulton et al. [21] presented an optimization model under uncertainty in order to make decisions about the redesign and relocation of emergency service facilities such as helicopters and location of ground ambulances during military stability operations. The optimum location of helicopter stations, hospitals and helicopter paths were investigated in their model so as to minimize expected travel time over all the possible scenarios. Erdemir et al. [22] presented an HEMS in New Mexico where it was not necessary for demands to only occur at nodes and they can also occur at routes. Erdemir et al. [23] developed a model for service facilities with demands on both nodes and paths to find the optimum location of helicopter stations in order to maximize covered demands. Erdemir et al. [24] suggested two covering models for the locations of ambulance, helicopter and transfer points. One of their models tried to minimize the sum of the establishment cost of these three facilities while covering all the demand points. The other model sought to

provide the maximum coverage of demands within the given total cost. Hosseiniyou and Bashiri [8] modeled the TPLP problem of Berman by considering a uniform distribution for demand point and solving it. Kalantari et al. [25] modeled the TPLP model by Berman et al. via considering fuzzy uncertainty at demand points and solved it by a heuristic method. Furuta and Tanaka [3] presented a developed P-median and P-center model for the location of joint helicopter and transfer points with deterministic demand points. In their model, Euclidean distance was considered in all distances. They also introduced a doctor-helicopter system in another study, in which a doctor was delivered to the patients by a helicopter. The objective function of their model was to maximize demand cover [26].

Table (1) shows the summary of the most important studies in TPLP context and the comparison with our study. Table (2) shows the most important studies on HEMS and the comparison with our work.

Table (1): Summary of the most important studies on TPLP

Author(s)	Parameter type	Topology	Objective function	Solution method	Explanations
Berman et al.[13]	Deterministic	Plane/network	Minisum/Minimax	Exact/heuristic	Origination
Berman et al.[14]	Deterministic	Network	Minisum	Heuristic	FTPLP
Berman et al. [12]	Deterministic	Plane/network	Minisum/Minimax	Exact	TPLP
Berman et al[15]	Deterministic	Plane/network	Minisum/Minimax	Heuristic	MLTP
Sasaki et al.[16]	Deterministic	Network	Minisum	Exact	FTPLP
Hosseiniyou et al.[8]	Uncertain / Stochastic	Plane	Minimax	Exact	TPLP
Kalantari et al.[25]	Uncertain / Fuzzy	Plane	Minisum	Heuristic	TPLP
Furuta et al.[3]	Deterministic	Network	Minisum/Minimax	Exact	FTPLP
This paper	Uncertain	Network	Minisum	Exact	FTPLP

Table (2): Summary of the most important studies on HEMS

Author(s)	Parameter type	Topology	Objective function	Time horizon	Solution method
Schuurman et al.[18]	Deterministic	Plane	Maximizing weighted demand coverage	Strategic	Exact
Branas et al.[19]	Deterministic	Network	Minimizing time average	Strategic	Heuristic
Fulton et al.[21]	Uncertain/scenario	Network	Minimizing time average regard to intensity of injury	Tactical	Exact
Erdemir et al.[23]	Deterministic	Network	Maximizing weighted demand coverage	Strategic	Exact
Erdemir et al.[24]	Deterministic	Network	Minimizing sum of establishment costs/Maximizing weighted demand coverage	Strategic	Heuristic
Furuta et al.[3]	Deterministic	Network	Minimizing the maximum time/Minimizing time based on weighted demand	Strategic	Exact
Furuta et al.[26]	Deterministic	Network	Maximizing weighted demand coverage	Strategic	Exact
This Paper	Uncertain	Network	Minimizing time based on weighted time	Strategic	Exact

### 3- Problem definition and mathematical model

Prior to presenting our mathematical model, we explain different possible transfer modes to the hospital. In the first mode, the injured would be transferred directly to the hospital by an ambulance. Figure (1) exposes this mode. In the second mode, the injured would be transferred to the helicopter station by an ambulance and then to the hospital by a helicopter. Figure (2) shows this mode. In the third status, the injured would be transferred to the helipad by an ambulance. At the same time, a helicopter would be sent out to the helipad and, after the ambulance and helicopter arrived at the



same location, the injured would be transferred to the hospital by a helicopter. This mode is shown in Figure (3). The key decision factor to select each mode is the transferring time of the injured to the hospital which is determined by the shortest time of each mode's transferring time ( $T_D$ ).  $T_1, T_2, T_3$  represent the transferring time from demand area to the hospitals by modes one, two or three, respectively.

$$T_D = \min(T_1, T_2, T_3) \quad (1)$$

In this model, the ambulance distances are calculated by rectilinear distance. Also, the helicopter distances are calculated by Euclidean distance because helicopters can travel directly between two points and do not face any obstacles. In this problem,  $(h_x, h_y)$  is the coordinate of the hospital,  $(r_x, r_y)$  is the coordinate of helipads and  $(s_x, s_y)$  is the coordinate of helicopter stations.

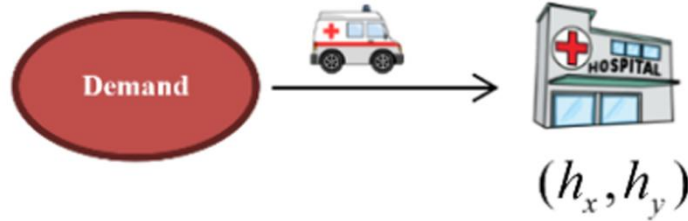


Figure (1): First mode of transferring the injured to the hospital

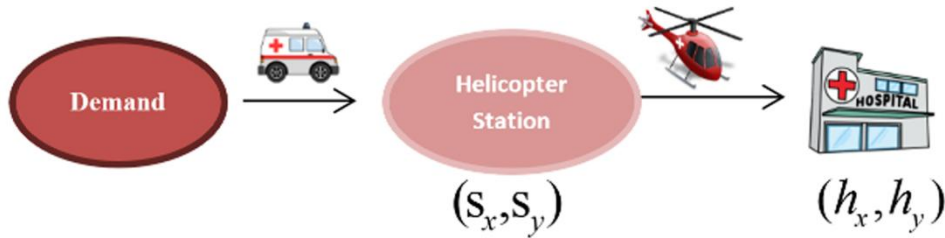


Figure (2): Second mode of transferring the injured to the hospital

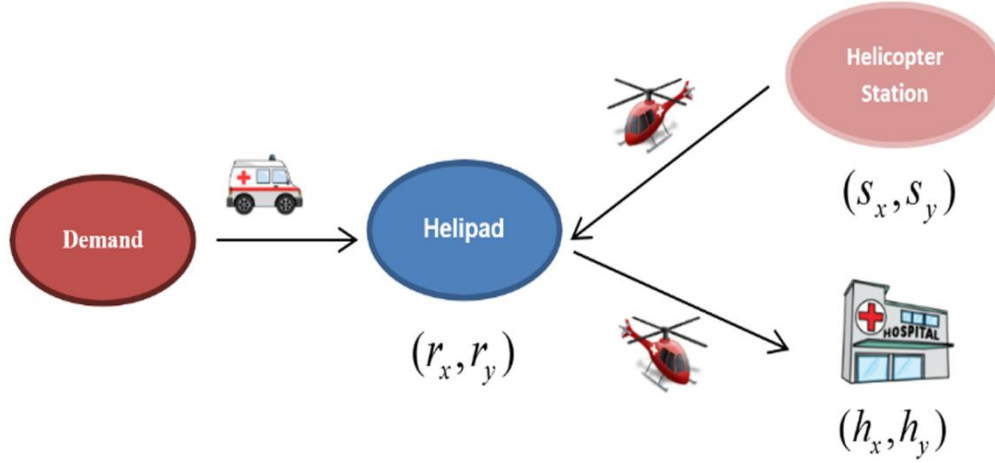


Figure (3): Third mode of transferring the injured to the hospital

The distance between helicopter station and hospital  $D_1$ , distance between helipad and hospital  $D_2$  and also distance between helicopter station and helipad  $D_3$  are calculated as follows:

$$D_1 = \sqrt{(h_x - s_x)^2 + (h_y - s_y)^2} \quad (2)$$

$$D_2 = \sqrt{(h_x - r_x)^2 + (h_y - r_y)^2} \quad (3)$$

$$D_3 = \sqrt{(s_x - r_x)^2 + (s_y - r_y)^2} \quad (4)$$

In this problem, it is assumed that each demand area has  $P_i = (U_i, V_i)$  coordination, in which  $U_i$  and  $V_i$  are independent stochastic variables with  $[a, b]$  uniform distribution. In other words, demand happens in a  $[a, b] \times [a, b]$  square-shaped area.

$$U, V \sim \text{uniform}[a, b] \quad (5)$$

Because  $U_i$  and  $V_i$  are independent random variables with a uniform distribution in  $[a, b]$ , so we have :

$$f_U(u) = \frac{1}{b-a}, f_V(v) = \frac{1}{b-a} \quad (6)$$

$$P = (U, V) \in [a, b] \times [a, b] \quad (7)$$

In fact, with the above-mentioned assumptions, we can consider that cities are square-shaped and the probability of incident at each point of this city is constant. To calculate the distance between the demand area and hospital  $d_i(h_x, h_y)$ , the demand point and helicopter station  $d_i(s_x, s_y)$  and demand area and helipad  $d_i(r_x, r_y)$ , we have:

$$d_i(h_x, h_y) = |U - h_x| + |V - h_y| \quad (8)$$

$$d_i(s_x, s_y) = |U - s_x| + |V - s_y| \quad (9)$$

$$d_i(r_x, r_y) = |U - r_x| + |V - r_y| \quad (10)$$

Now, we can calculate the expected value of distance between the helipad and the hospital as follows:

$$E[d_i(h_x, h_y)] = E[|U - h_x| + |V - h_y|] = E[|U - h_x|] + E[|V - h_y|] \quad (11)$$

)

We also have:

$$f(h_x) = E[|U - h_x|] = \int_{-\infty}^{+\infty} |u - h_x| f_u(u) d_u = \frac{1}{b-a} \int_a^b |u - h_x| d_u \quad (12)$$

$$f(h_x) = \begin{cases} -h_x + \frac{a+b}{2} & h_x \leq a \\ \frac{(h_x - a)^2 + (h_x - b)^2}{2(b-a)} & a \leq h_x \leq b \\ h_x - \frac{a+b}{2} & h_x \geq b \end{cases} \quad (13)$$

$f(h_y)$ ,  $f(r_x)$ ,  $f(r_y)$ ,  $f(s_x)$  and  $f(s_y)$  is calculated as above.

In this section, an integer mathematical modeling is developed to solve the problem. We assume that demand areas and hospital locations are pre-determined. Our objective is to determine the optimum location of helicopter stations and helipads in a way to minimize the transfer time from demand areas to hospitals under different transfer modes. In order to model the problem, we define these parameters and decision variables:

### 3-1- Sets and parameters

$I$ : Set of demand points indexed by  $i$

$J$ : Set of candidate locations for helipads indexed by  $j$

$K$ : Set of candidate locations for helicopter stations indexed by  $k$

$C_t$ : Establishment cost of each helipad

$C_s$ : Establishment and mobilization cost of each helicopter station

$B$ : Total budget of the plan

$h_i$ : Demand weight of each demand area  $i$

$v$ : Helicopter speed

$w$ : Ambulance speed

### 3-2- Decision variables

$x_j$ : 0-1 location variable; 1 if helipad is established at node  $j$ , 0 otherwise

$y_k$ : 0-1 location variable; 1 if helicopter station is established at node  $k$ , 0 otherwise

$u_i$ : 0-1 allocation variable; 1 if demand  $i$  is met by the ambulance (first mode), 0 otherwise

$l_{ik}$ : 0-1 allocation variable; 1 if demand  $i$  is met by station  $k$  (second mode), 0 otherwise

$\omega_{ijk}$ : 0-1 allocation variable; 1 if demand  $i$  is met by the combination of transfer point  $j$  and station  $k$  (third mode), 0 otherwise

$T_{ijk}$ : Auxiliary variable which is the maximum value between ambulance arrival time to helipad and helicopter arrival time from base to transfer point  $j$

### 3-3- Mathematical model

$$\min \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} h_i \left\{ \left[ \frac{f(h_{x(i)}) + f(h_{y(i)})}{w} \right] u_i + \left[ \frac{f(s_{x(i)}) + f(s_{y(i)})}{w} + \frac{\sqrt{(h_{x(i)} - s_{x(k)})^2 + (h_{y(i)} - s_{y(k)})^2}}{v} \right] l_{ik} \right. \\ \left. + \left[ T_{ijk} + \frac{\sqrt{(h_{x(i)} - r_{x(j)})^2 + (h_{y(i)} - r_{y(j)})^2}}{v} \right] \omega_{ijk} \right\} \quad (14)$$

$s.t.$

$$l_{ik} \leq y_k \quad i \in I, k \in K \quad (15)$$

$$\omega_{ijk} \leq x_j \quad i \in I, k \in K, j \in J \quad (16)$$

$$\omega_{ijk} \leq y_k \quad i \in I, k \in K, j \in J \quad (17)$$

$$u_i + \sum_{k \in K} l_{ik} + \sum_{j \in J} \sum_{k \in K} \omega_{ijk} = 1 \quad i \in I \quad (18)$$

$$\sum_{j \in J} C_t x_j + \sum_{k \in K} C_s y_k \leq B \quad (19)$$

$$T_{ijk} \geq \frac{f(r_{x(j)}) + f(r_{y(j)})}{w} \quad i \in I, j \in J, k \in K \quad (20)$$

$$T_{ijk} \geq \frac{\sqrt{(r_{x(j)} - s_{x(k)})^2 + (r_{y(j)} - s_{y(k)})^2}}{v} \quad i \in I, j \in J, k \in K \quad (21)$$

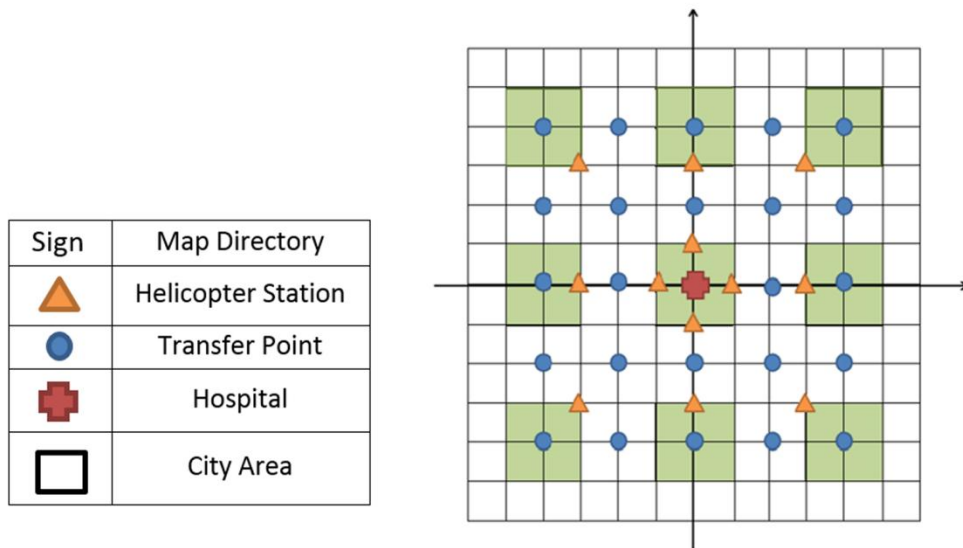
$$\begin{aligned} x_j \in \{0,1\} \quad y_k \in \{0,1\} \quad u_i \in \{0,1\} \\ l_{ik} \in \{0,1\} \quad \omega_{ijk} \in \{0,1\} \end{aligned} \quad i \in I, j \in J, k \in K \quad (22)$$

The objective function (14) is the total weighted demand transfer time under different modes. Constraint (15) implies that demand  $i$  can be assigned to the second mode if a helicopter station is located at  $k$ . Constraints (16) and (17) together imply that demand  $i$  can be assigned to the third mode if a helipad is established at node  $j$  and a helicopter station is established at node  $k$ . Constraint (18) states that each demand is assigned to only one of these three modes. Constraint (19) is the total budget constraint on the construction of helipads and helicopter stations. Constraints (20) and (21) are used to linearize the objective function in the third mode which represents that the ambulance's and helicopter's meeting time is equal to the maximum arrival time of each of these facilities to the helipad. Constraints (22) are the standard binary constraints.

#### 4- Numerical example

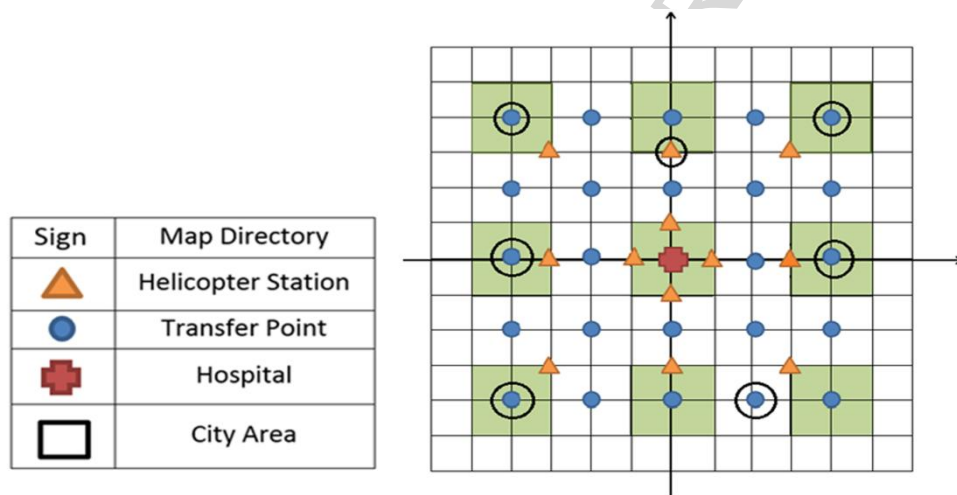
In order to represent this model's performance, first, a simple example is given and, then, application of this model in a real case is discussed.

In Figure (4), green squares represent demand areas which are distributed in  $2 \times 2$  dimension in a coordinate plane. Blue circles are helipads' establishment candidate points and orange triangles are helicopter stations' establishment candidate points. The hospital is considered at the coordination origin point. There are 24 suggested points for helipads and 12 for helicopter stations.



Figure(4): Candidate points for helicopter station and helipad

By considering 23,000,000,000 Rial as the budget, 2,000,000,000 Rial for each transfer point establishment, 10,000,000,000 Rial for each helicopter station establishment, the helicopter speed of 200 km/h, and ambulance speed of 40 km/h, the optimum value of the objective function was obtained as 0.537 by the GAMS software and points in Figure (5) were activated:



Figure(5): Activated points for helicopter station and helipad

In Table (3) the comparison of transfer times in two modes is shown. According to Table (3), a noteworthy decrease in transfer time is observed by implicating HEMS and increasing budget. Also, we can see in Figure (6) that by increasing the budget, the number of activated helipads and helicopter stations increases; however, in some cases, this increase does not influence the number of activated helipads and helicopter stations. According to Figure (7), the objective function, by increasing the budget, starts to decrease moderately; however, in some cases, particularly higher budgets, the objective function does not change.

Table (3): Sensitivity analysis of assigned budget

Status	Assigned budget ( in billion p.i.d)	Objective function of time or number of helipad points	Number of helicopter stations
Without implementing HEMS	-	2.625	-
With HEMS	13	1.577	1
	18	0.715	1
	23	0.537	1
	28	0.432	1
	33	0.432	1
	43	0.418	2
	63	0.418	2

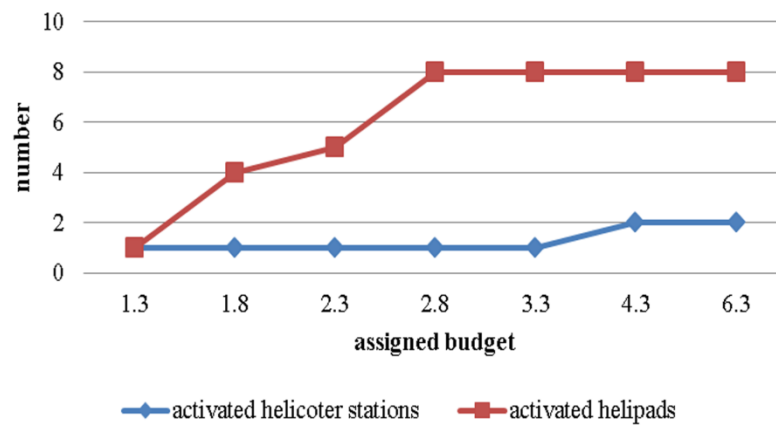


Figure (6): Changing activated helipads and helicopter stations with increasing budget

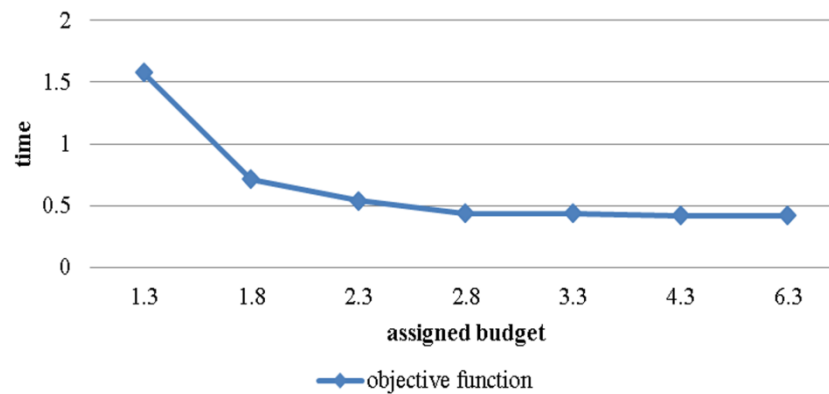


Figure (7): Changing objective function (time) with increasing budget

### 5- Case study - Lorestan Province

Lorestan Province is one of the western provinces in Iran, with the area of 28294 km<sup>2</sup> and population of more than 1,700,000. According to the evidence, there are too many accidents happening on the roads of this province, and with respect to active faults in Zagros Mountains and potential flooding in the south part of this province, especially in Pol Dokhtar, Lorestan is among the 10 most accident-prone provinces of Iran. Therefore, it seems critical to implement a suitable emergency healthcare system in this province. In Table (4), the most important cities of Lorestan Province are listed based on their population and its related weight. “Shohada-e-Ashayer” Hospital is located in Khorramabad City which can respond to traumatic patients. The objective community of this research was the accident injured patients needing to be transferred to Shohada-e-Ashayer Hospital as soon as possible.

Table(4): Population of important cities in Lorestan Province

No.	City name	City population	Population weight ( $h_i$ )
1	Khorramabad	354855	0.331
2	Borujerd	245737	0.229
3	Dorud	100977	0.094
4	Kuhdasht	111736	0.104
5	Aligudarz	89520	0.083
6	Nur Abad	62190	0.053
7	Azna	41706	0.039
8	Aleshtar	33133	0.031
9	Pol Dokhtar	32594	0.030
<b>Total population</b>		1072448	1

Each of these 9 cities in Table (4) is inscribed in a square with respect to their area (Figure 8). Each city's weight ( $h_i$ ) was calculated by dividing population of each city by its total population. According to the comments of experts, these 8 points were considered as helicopter station candidate points: Azna, Aligudarz, Dorud, Borujerd, Aleshtar, Nur Abad, Kuhdasht and Pol Dokhtar. Also, these 18 points were considered as helipad suggested points: Beyranvande Junubi, Razan, Zargaran Olia, Dorud, Azna, Aligudarz, Borujerd, Oshtarinan, Varayeneh, Aleshtar, Firuzabad, Farhad Abad, Nur Abad, Sarab-e-Dowreh, Kuhdasht, Afrineh, Romeshgan and Pol Dokhtar.

In addition, all the coordinates of the considered points were calculated by Google Earth v. 6. The total budget for this plan was considered 130,000,000,000 Rial. Each transfer point establishment cost was estimated as 2,000,000,000 Rial and the cost of each helicopter station with its helicopter was 60,000,000,000 Rial.



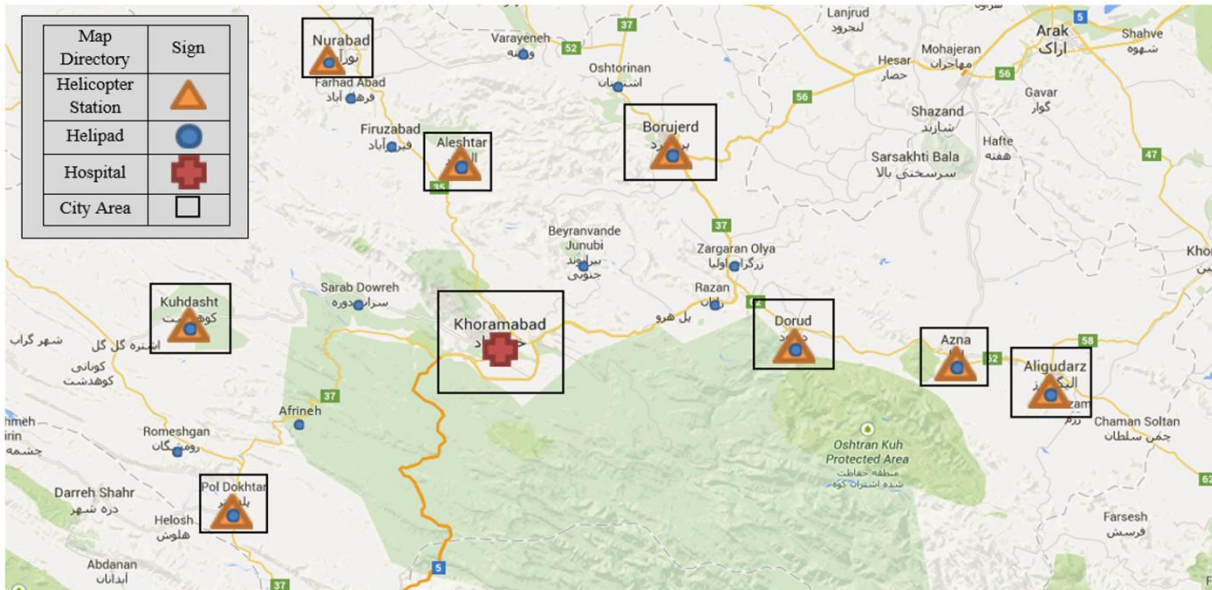


Figure (8): Lorestan Province's helicopter stations and helipad candidate points

The problem was solved by the GAMS software on a computer with these specifications: Intel Core i5- 2.4GHz CPU and 4GB RAM. In the mathematical model, the objective function was equal to 32.4 min. The model activated two helicopter stations and five helipads. The potential cities for establishing helipads were Aligudarz, Borujerd, Aleshtar, Farhad Abad and Pol Dokhtar. Also, Dorud and Kuhdasht were nominated for establishing helicopter stations. For instance, if an injury occurred in Khorramabad, it was better to use ground ambulance for transferring the patients to the hospital. Also, if any injury occurred in Dorud, the fastest way to carry patients to the hospital was the second mode which was carrying patients by an ambulance to the Dorud helicopter station and, then, to the hospital by a helicopter. If any injury occurred in Azna, it was better to use the third mode where the ambulance and helicopter both arrived at the Aligoudarz helipad and, from there, the patient was carried to the hospital by a helicopter. Table (5) shows how each demand area is assigned to each of the three modes.

Table (5): Transfer mode of cities in Lorestan Province

No.	Demand point	Status	Active helicopter station	Active transfer point
1	Khorram Abad	First	-	-
2	Dorud	Second	Dorud	-
3	Azna	Third	Dorud	Aligudarz
4	Aligudarz	Third	Dorud	Aligudarz
5	Borujerd	Third	Dorud	Borujerd
6	Aleshtar	Third	Kuhdasht	Aleshtar
7	Nur Abad	Third	Kuhdasht	Farhad Abad
8	Kuhdasht	Second	Kuhdasht	-
9	Pol Dokhtar	Third	Kuhdasht	Pol Dokhtar

Figure (9) shows each demand area's transfer mode in this province according to Table (5).

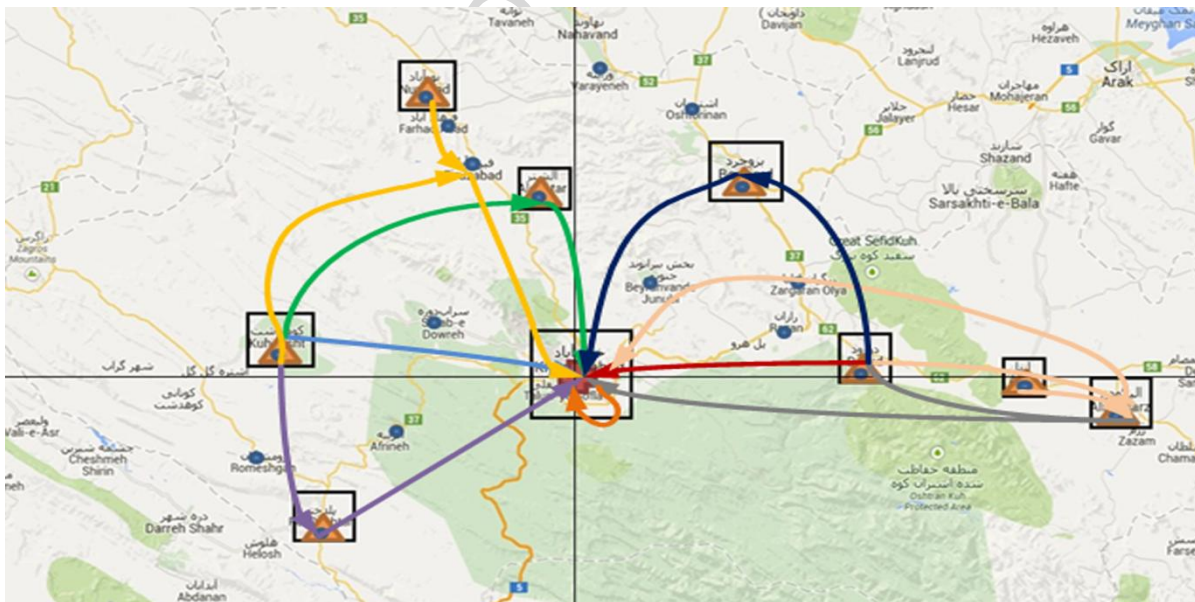


Figure (9): Transfer modes from demand areas to hospitals

## 6- Conclusions and recommendations

In this paper, an integrated helicopter station and helipad location model was developed by considering uncertainty. Some points were geographically located in mountainous areas or those with high population density, which could make helicopter landing procedure difficult. Thus, it seemed necessary to establish helipads. There were three modes to transfer injuries to the hospital; The first mode was to transfer injuries directly to the hospital by an ambulance, the second was to transfer

them to the helicopter station by an ambulance and, then, to the hospital by a helicopter and the third was to transfer them to helipad by an ambulance and, then, to the hospital by a helicopter. In this paper, the demand area followed a uniform distribution. Demand areas were considered for decreasing computational errors occurring when the distance travelled between cities was assumed as the distance between their areas' center points. The model objective function attempted to minimize the sum of transfer times from demand areas to the hospital. To evaluate the model, a simple numerical example was set and its results proved the advantages of the HEMS system in comparison with the traditional system. In addition, based on the case study performed in Lorestan Province, optimum places to establish helipads and helicopter stations were determined and allocation type of each facility to demand regions was also specified. Future studies can (1) consider a capacity for each emergency facility, (2) implement the HEMS system by assuming disruption in the network, (3) study more comprehensive cases at various points, different modes and more realistic conditions, (4) consider the distribution of the ambulances in the demand areas and its impact on the model and (5) consider uncertainty on the time of ground EMS services due to geographic issues.

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