International Journal of Industrial Engineering & Production Research March 2020 Vol. 31, No. 1: 63- 74
DOI: 10.22068/ijiepr.31.1.63

RESEARCH PAPER

A Bi-Objective Dynamic Reliable Hub Location Problem With Congestion Effects

Parviz Fattahi*[1] & Zohreh Shakeri Kebria[2]

Received 28 January 2020; Revised 30 January 2020; Accepted 1February 2020; Published online 31 March 2020

ABSTRACT
This study solves a new model of hub locating with respect to the reliability and importance of flow congestion on hub nodes in a dynamic environment. Each node is considered as a hub, whose communication path to another non-hub node has specific reliability. In order to reduce input flow to any hub and avoid creating unsuitable environmental and traffic conditions in that area, efficiency capacity is allocated to each hub, which is subject to a penalty in case of exceeding this amount. This model is also capable of deciding whether hubs are active or inactive in each period; therefore, hub facilities can be established or closed due to different conditions (such as changes in demand, legislative, etc.). The model is nonlinear and bi-objective; the first goal is to reduce transportation costs, hub rental fees, and extra flow congestion penalties on hub nodes and the second goal is to increase the minimum designed network reliability. After the linearization of the model, by using ε-constraint method, the optimal boundary is obtained. Moreover, to demonstrate the performance of the model, IAD dataset is used for solving the problem. To evaluate the model, sensitivity analysis is presented for some of the important parameters of the model.

KEYWORDS: *Dynamic hub locating; Reliability; Flow congestion; ε-constraint method.*

1. Introduction

Facility locating is one of the strategic decisions in logistics issues that remains unchanged in different periods and influences critical operational decisions [1]. One of the most important points in the locating problem in logistics is the hub networks locating. Hub networks consist of hubs and non-hubs nodes, where hubs represent a location where all transport-related activities are distributed and that other commodity logistic services at international or national levels are carried out by several hunters. Commodities move (or flow) from non-hub nodes to hubs, are collected and categorized in hub nodes, and then are sent to specified destinations. Due to the increasing growth of economic competition, different conditions (such as seasonal changes), and changes in flows, some networks are considered to be dynamic (multi-period), concluding optimal operational decisions with respect to flexibility in strategic decisions. Hub networks enjoy important applications in transportation and communication systems (such as passenger services, post services, emergency services, and telephone networks). A number of issues and problems associated with hub locating are the assignment of non-hubs nodes to only one hub [2-4], the assignment of non-hub nodes to more than one hub [5], the permissibility of direct communication between non-hub nodes, continuous or discrete hub locating [6], limitations on the number of hubs [7, 8], and hubs with a capacity or non-capacity [9-11]. One advantage of hub networks can be economies of scale (in hub networks due to the integration of multiple demand flows in a larger shipment and with larger vehicles, the cost per unit of flow transmission decreases.) and territory saving (facilities in hub have the ability to perform multiple simultaneous tasks; thus, the cost of performing multiple simultaneous works at these centers is more cost effective than that of doing activities separately). In some cases, these networks are also susceptible to disadvantages: longer travel times and higher costs for some

* Corresponding author: *Parviz Fattahi*
p.fattahi@alzahra.ac.ir

1. *Alzahra University lzahra University, North Sheikh Bahaee St., Deh-e Vanak, Tehran, I. R. of Iran*
2. *Candidate Alzahra University.*

routes, high risk at centers (due to overcrowding, etc.), and disruptions in the entire system.

One of the first locating hub articles was published in 1996 by O'kelly [12, 13]. Having defined the hub networks, he developed several location models for hubs and outlined an empirical example for connecting this model to an understanding of fast delivery networks. In 2010, Contreras et al. [14] examined hub locating in dynamic conditions (multi-period) and used the branch and bound algorithm along with the Lagrangian Relaxation to carry out calculations for 100 nodes in 10 periods. In the same year, Gelareh et al. proposed a mixed-integer linear programming hub network model in a competitive environment with the aim of maximizing market share by reducing the cost of transportation and service time [15]. In 2011, Makui et al. [16] (2011) presented an article called "a robust optimization model for capacity-hub locating". The objective function of their model consists of three parts. The first part is to minimize the cost of establishing a hub and transporting commodities. The second part minimizes the maximum distances, and the third part minimizes all the time needed to process commodities. In their model, demand was considered as an indeterminate parameter. These parameters also become indeterminate and are defined in different scenarios due to the fact that the parameters are affected by demand according to the model's capacity limitations to achieve the goals. They attempted to solve the problem by defining different scenarios and imposing limitations on the model's capacity.

In 2011, Gelareh and Nickel [17] applied a model for locating multi-assignment hubs to design an urban transport network. In this paper, they used AP (Australian Post) databases for numerical examples and Benders decomposition to solve the problem. Taghipourian [18] et al. (2012) applied the hub location to air transportation networks due to weather and emergency conditions. To approximate this problem to reality, the concept of fuzzy was used to reduce the total cost of the system. Another new discussion that has been proposed concerned the possible failure and disruptions in paths connecting to hubs or inside hubs. In an article by Eghbali et al. [19] in 2014, a multi-objective single-assignment model was proposed to locate a covering hub that attempts to make a balance between total costs and the number of related links in the network; based on the constraint definition, the minimum network reliability increases. Ghodratnama et al. [20] examined a randomized scenario-based problem and hubs with open and closed modes by minimizing costs. In this article, the number of customers and hubs was predefined, and a variety of hubs like median, center, and covering were analyzed. In hub networks, the main suppliers may have several dedicated facilities leased for a specific horizon. Therefore, they must decide based on the hub location, the period when a rental contract starts and ends, and the flow path along the planning horizon to minimize total operating expenses. Gelareh et al. (2015) [21] presented a mathematical model for the non-capacity hub location problem with multi-assignment, multi-period, and capacity limitation. This article covers several features in the field of maritime and land transport. In the same year, Yang and Chiu [22] studied the hub network design with flow congestion effects and uncertain demand with a two-stage stochastic problem. In the first step, the decision was made to locate the hubs and, in the second step, the allocation and determination of flows were done. Bashiri et al. [23] introduced a mobile p-hub locating problem in a dynamic environment with mobility facilities as hub nodes that move in different periods to meet demands. This model is very useful for emergency needs in the real world.

Regarding the literature review, an attempt has been made to model the bi-objective dynamic reliable hub location problem with congestion effects (BO - DRHLP) in order to implement real-world cases in the model. In the next section, the BO-DRHLP model is proposed. In Section 3, the results of numerical examples and sensitivity analysis are examined, and the conclusions are presented in the final section.

2. BO-DRHLP Model

In this section, the dynamic (multi-period) hub locating model (multi-period) is described with restrictions on network reliability and hub flow congestion. According to the dynamic environment and different demands in each period, the active or inactive hubs are studied in each period and an attempt is made to create a proper balance between the existing costs, flow congestion, and reliability in this network. The assumptions of the problem are as follows:

- This problem has seasonal periods.
- The maximum number of potential hubs that can be used in each period is specified.
- In each period, active rental hubs in previous periods can be disabled according to model requirements.

- In each period, inactive hubs in previous periods can be activated as demand and model requirements increase.
- Direct connection between non-hub nodes is not possible.
- The problem of hub assignment is of single-allocation type.
- The discount factor is applied to hub transportation paths.
- Hub nodes and connecting paths have specified reliability.
- Each hub has a specified efficiency capacity that enters the model according to location and its equipment. Fines are estimated based on the difference between two effective capacity and imposed capacity, while a greater capacity is imposed on the hubs.

The network used in this model is an incomplete graph. The network between hub nodes and the network between hub and non-hub nodes is complete and fully connected; however, there is no direct connection between non-hub nodes. This network is represented by $G = (V, E)$, which has V nodes; k and l indexes constitute a set of hub nodes; i and j indexes refer to non-hub nodes. E shows the edges between hub and non-hub nodes and between hub nodes. Parameters, variables, two objective functions, and other constraints are defined in the following.

Parameters:

Moving cost from source i to destination j through two hubs k and l during period t	c_{tij}^{kl}
Fixed cost of establishing hub k in period t	ec_{tk}
Closing cost hub k in period t	cc_{tk}
Profit from facilities flexibility in the closed hub in period t	ms_t
The unit penalty for flow congestion at hub k	ρ_k
Reliability between hub node k and non-hub node i	Re_{ik}
Reliability of hub k	re_k
Discount Factor for paths between hubs	α
Discount Factor for paths between hub and non-hub nodes	β
The effective capacity for hub k that can work well	U_k
Big Number	M
	Variables
Binary variable of nodes i and j connection via hub k and l in period t	x_{tij}^{kl}
Binary variable to establish new hub k in period t	p_{tk}
Binary variable to close hub k in period t	q_{tk}
Minimum amount between the number of close and established hubs in period t	z_t
The amount of flow that exceeds the efficiency at node k	e_k
Binary variable of connecting node i to hub k in period t	y_{tik}
Minimum reliability for any path between source and destination	W

The problem has two objective functions. The first objective function is to minimize costs, and the second objective function is to maximize the minimum reliability.

$$Objective\ 1)\quad Min \sum_t \sum_i \sum_j \sum_k \sum_l c_{tij}^{kl} + \sum_t \sum_k ec_{tk}\, p_{tk} + \sum_t \sum_k cc_{tk}\, q_{tk} - \sum_t ms_t\, z_t + \sum_k \rho_k\, e_k \tag{1}$$

$$Objective\ 2)\quad Max\ W \tag{2}$$

$$\sum_k y_{tkk} \le pp_t \quad \forall t \tag{3}$$

$$\sum_k \sum_l x_{tij}^{kl} = 1 \quad \forall i,j,t \tag{4}$$

$$2x_{tij}^{kl} \le y_{tjl} + y_{tik} \quad \forall t,i,k,l,j \tag{5}$$

$$y_{tik} \le y_{tkk} \quad \forall t,i,k \tag{6}$$

$$\sum_k y_{tik} = 1 \quad \forall t,i \tag{7}$$

$$p_{tk} - q_{tk} = y_{tkk} - y_{t-1,kk} \quad \forall t,k \tag{8}$$

$$p_{tk} + q_{tk} \le 1 \quad \forall t,k \tag{9}$$

$$z_t = \min\left(\sum_k p_{tk}, \sum_k q_{tk}\right) \quad \forall t \tag{10}$$

$$Re_{ik} re_k^{1-\beta} Re_{kl}^{1-\alpha} re_l^{1-\beta} Re_{jl} \ge W x_{tij}^{kl} \quad \forall t,i,k,l,j \tag{11}$$

$$\sum_i \sum_j \sum_l d_{ij}\left(x_{tij}^{kl} + x_{tij}^{lk}\right) - \sum_i \sum_j d_{ij} x_{tij}^{kk} - e_k \le U_k y_{tkk} \quad \forall t,k \tag{12}$$

$$x_{tij}^{kl}, y_{tkk}, p_{tk}, q_{tk} \in \{0,1\};\ z_t \ge 0\ \&\ integer \tag{13}$$

The first objective function shows the total cost minimization. Part I calculates transportation cost from source node i to destination node j through two hubs k and l. Establishing or renting new hubs and deactivating hubs in each period is costly for the company. These costs are shown in the second and third parts of objective function. While closing hubs impose cost on the company, using its equipment and resources in the hubs that are going to be activated has benefits for the company. This value is shown as a profit from facilities flexibility based on the minimization of the number of hubs being reopened and deactivated hubs that are shown in the fourth part of the objective function. Part 5 of the first objective function shows the penalties resulting from injecting additional flows to hubs. Each hub has an efficient capacity amount that receives greater load pressure.

The second objective function is to maximize the reliability of the entire network based on hub nodes reliability and connecting paths. This value is calculated based on the maximization of network minimum reliability (MaxMin). W is the lowest amount of network reliability that the model tries to maximize.

Constraint (3) represents the maximum allowed amount of hub activation in each period. Constraint (4) ensures that each pair of source and destination nodes is connected to one or two hubs. Constraint (5) indicates that the path between two nodes i and j is established by two hubs k and l in period t in case both k and l are open in this period, node i connects to hub k, and node j connects to hub l. Constraint (6) ensures that node i can be connected to hub k in period t when node k is in the set of hubs in period t. Constraint (7) shows that the problem is single-valued, and each node i can be connected to only one hub. Equality in Constraint (8) indicates whether the hub is active or not in period t. The hub that was not active in previous period can be reactivated, and the hub that was active in the past period can be disabled. Constraint (9) indicates that each hub should have maximum one decision about getting active or inactive in each period. The amounts of p_{tk} and q_{tk} will be zero If the hub is active (inactive) in a period and wants to participate without changing the mode in the next period. Constraint (10) calculates the number of possible movements from the minimum amount of open or close hubs, as explained in the objective function related to the facility flexibility profit. The minimum value between p_{tk} and q_{tk} is considered because, in the case of closing two hubs and opening one hub, the equipment of one closed hub is used to activate the new hub. If two hubs are opened and one hub is closed, we only have one unit equipment for supplying hubs, and the equipment for the other hubs must be purchased. Constraint (11) calculates the minimum network reliability by multiplying the reliability between the connecting paths and the reliability of the used hubs. Constraint (12) calculates the flow congestion level that penalizes flows more than the effective capacity of the hub in each period.

The total cost parameter for moving is calculated through Eq. (14).

$$c_{tij}^{kl} = \beta c'_{tik} + \alpha c'_{tkl} + \beta c'_{tjl} \tag{14}$$

where c'_{tik} and c'_{tjl} show the moving cost between the hub and non-hub nodes in period t, and c'_{tkl} represents the moving cost between two hub nodes in period t. α and β are edge discount coefficients in which α has usually a higher value.

Since Constraints 10 and 11 are the nonlinear factors of the model, Constraints 15 and 16 are used to linearize Constraint 10; in addition, Constraint 17 is used instead of Constraint 11.

$$z_t \leq \sum_k p_{tk} \quad \forall t \tag{15}$$

$$z_t \leq \sum_k q_{tk} \quad \forall t \tag{16}$$

$$W \leq Re_{ik} re_k^{1-\beta} Re_{kl}^{1-\alpha} re_l^{1-\beta} Re_{jl} + \left(1 - x_{tij}^{kl}\right) M \quad \forall t, i, k, l, j \tag{17}$$

3. Solution Approach for BO-DRHLP

There are two commonly used approaches to solving bi-objective models: weighted sum method and ε-constraint method. According to the articles (Mavrotas 2009, Steuer 1986, Miettinen 1998), it is proved that ε-constraint method is superior to the weighted sum method [24-26]. This is mainly due to the fact that ε-constraint method has computational efficiency. In this method, one of the objective functions is optimized and other objectives are incorporated into a set of constraints, as shown in Eq. (18).

To solve the dynamic bi-objective hub location model considering reliability and effects of flow congestion, the ε-constraint method has been used. In this method, one of the objective functions that is of greater importance is considered as the main objective function of the model, and other functions are considered as constraints with lower or upper limits on the basis of minimization or maximization. In this model, the first objective function (cost minimization) is defined as the main objective function, and the second objective function is defined as the subordinate objective function in limitations. The BO-DRHLP model is rewritten as follows:

$$\min function = function\,1 \tag{18}$$

$$s.t.$$

$$function\,2 \geq \varepsilon \tag{19}$$

$$Equation: (3) - (13) \tag{20}$$

3.1. Numerical example

Iranian Aviation Dataset (IAD) has been used to solve this model. The IAD was introduced by Karimi and Bashiri [27] in 2011. These data include cost and flow matrices in addition to the cost of creating hubs. Flow data are calculated from two criteria of tourism and industry. Based on these criteria, the importance of cities is calculated by TOPSIS (A technique for ordering preference with similarity to the ideal solution). Term TOPSIS was first introduced by Hwang and Yoon [28] in 1991. TOPSIS is a very technical and robust decision process that presents the prioritization of alternatives by creating them as an ideal solution. The alternative chosen by this method should have the shortest distance from the positive ideal and the largest distance from the negative ideal [29]. Advantages of using this method include qualitative and quantitative features, cost evaluation, information usefulness at the time according to a significant number of proceedings, quick and simple implementation, the ability to change input data easily and respond to the system based on these changes, the comparative relations used for data normalization, distance calculation and determining the weight of indicators based on problem information [30]. In IAD dataset, the flow of data between cities is calculated considering the population of each city and its importance. Information about distance and fixed costs has been taken from Iranian Airport Company.

Tab. 1. Existing flows between network nodes

D(Km)	Abadan	Ahvaz	Arak	Ardabil	Bandar Abbas	Birjand	Bojnurd	Bushehr	Chabahar	Esfahan	Gorgan
Abadan	0	123	704	1401	1217	1889	1710	420	2088	868	1394
Ahvaz	123	0	581	1305	914	1918	1587	334	2153	445	1271
Arak	704	581	0	843	1245	1606	1006	868	1872	288	690
Ardabil	1401	1305	843	0	1925	1814	1080	1610	2552	1030	764
Bandar Abbas	1217	914	1245	1925	0	757	1627	927	537	822	1731
Birjand	1889	1918	1606	1814	757	0	614	1599	1166	1173	1050
Bojnurd	1710	1587	1006	1080	1627	614	0	1941	1900	1152	316
Bushehr	420	334	868	1610	927	1599	1941	0	1798	580	1625
Chabahar	2088	2153	1872	2552	537	1166	1900	1798	0	1584	2216
Esfahan	868	445	288	1030	822	1173	1152	580	1584	0	836
Gorgan	1394	1271	690	764	1731	1050	316	1625	2216	836	0

This database has 37 important cities in which a number of important cities and their information are used to solve the model. This information is shown in Table 1. Other parameters that are not present in this database are randomly generated. In Table 2, some of input parameters of the problem have been shown. The reliability parameters of hub nodes have uniform distribution U (0.8, 1), and the paths between nodes have uniform distribution U (0.7, 0.9). In this model, four seasonal periods are considered. The location of important cities is shown in Figure 1. Introduced cities are important cities in Iran, which usually have high loads and demands, and each of them is a reasonable choice for the hub.

Tab. 2. Input parameters to problem

t	1	2	3	4
ms(t)	30	50	60	100
pp(t)	2	3	4	3
alpha(t)	0.2	0.5	0.6	0.3

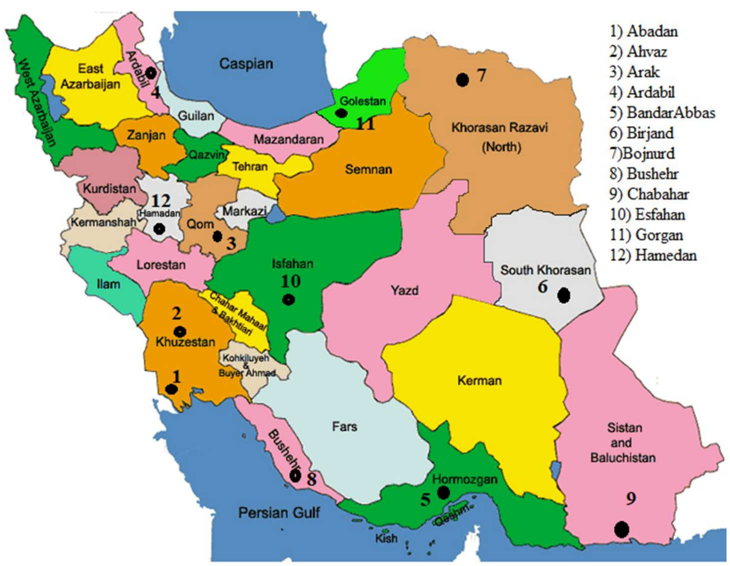

Fig. 1. Location of network nodes and flows

The problem is solved for 10, 11, and 12 nodes in GAMS, and the results are presented in Table 3. In this table, first, column shows the number of problems, the second column shows the number of available nodes, the third column shows the period of time, the fourth column shows the selected hubs, the fifth column shows the nodes assigned to each hub nodes, and the last column shows the objective function value.

Tab. 3. Solved examples in GAMS software

Num	N	t	Hub	Allocation	Obj(e^10)
1	10	1	5,10	5-1,2,3,8,9 10-4,6,7	2.129
		2	5,10	5-1,3,6,9 10-2,4,7,8	
		3	5,10	5-1,3,6,9 10-2,4,7,8	
		4	5,10	5-1,2,,3,9 10-4,6,7,8	
2	11	1	5,10	5-1,3,9 10-2,4,6,7,8,11	2.813
		2	5,10,11	5-1,3,6,9 10-2,4,8 11-7	
		3	1,10,5,11	1- 10-2,4,8 5-3,6,9 11-7	
		4	5,10,11	5-1,3,9 10-2,4,6,8 11-7	
3	12	1	5,10	5-1,3,7,9 10-2,4,6,8,11,12	2.978
		2	1,5,10	1-8,11 5-3,7,9 10-2,4,6,12	
		3	1,2,5,10	1-8,11 2-3,7 5-6,9 10-4,12	
		4	1,5,10	1-8,11 5-3,7,9 10-2,4,6,12	

The solved example in the first row of Table 3 is shown in Fig. 2. Figure 2 shows that the number of hubs required has not changed in different periods; however, in different seasons, some of customers assigned to each hub have been moved. In the first period, Nodes 1, 2, 3, 8, and 9 are assigned to Hub 5; however, in the second period, Node 6 is connected to Hub 5, and Nodes 2 and 8 are connected to Hub 10. Regarding different seasons, permanent customers with constant hubs regardless of season changes can be identified. For example, Nodes 1, 3, and 9 are always connected to Hub 5, and Nodes 4 and 7 are always connected to Hub 10, which is a loyal customer for the hub. Therefore, applying this model, we can find which hubs are active in all seasons and which of them essential hubs. In addition, the fixed and variable customers of each hub can be identified and efforts can be made to increase the reliability of their connection to hubs.

Another issue that can be considered in this model is limitation Constraint (3). In case this constraint, which is smaller than or equal to its counterpart, is applied, it would make the model decide on the number of optimal hubs in each period according to the number of potential hubs in the same period. If this constraint applies as an equal constraint, it would force the model to choose the number of potential hubs. Since the required hubs are low, the model will be forced to inflict more load on the hub; in addition, if the required hubs are large in number, an extra charge is incurred to the model. For example, in the first period, the answers are the same; however, in the second period, since the model has had to open three hubs, hub 2 has been active in addition to Hubs 5 and 10. This indicates that in case the network needs to create a new capacity to meet customers' demands in Period 2, it is best to activate Hub 2. The model status in different periods and the conversion of Constraints 3 to equality is shown in Fig. 3.

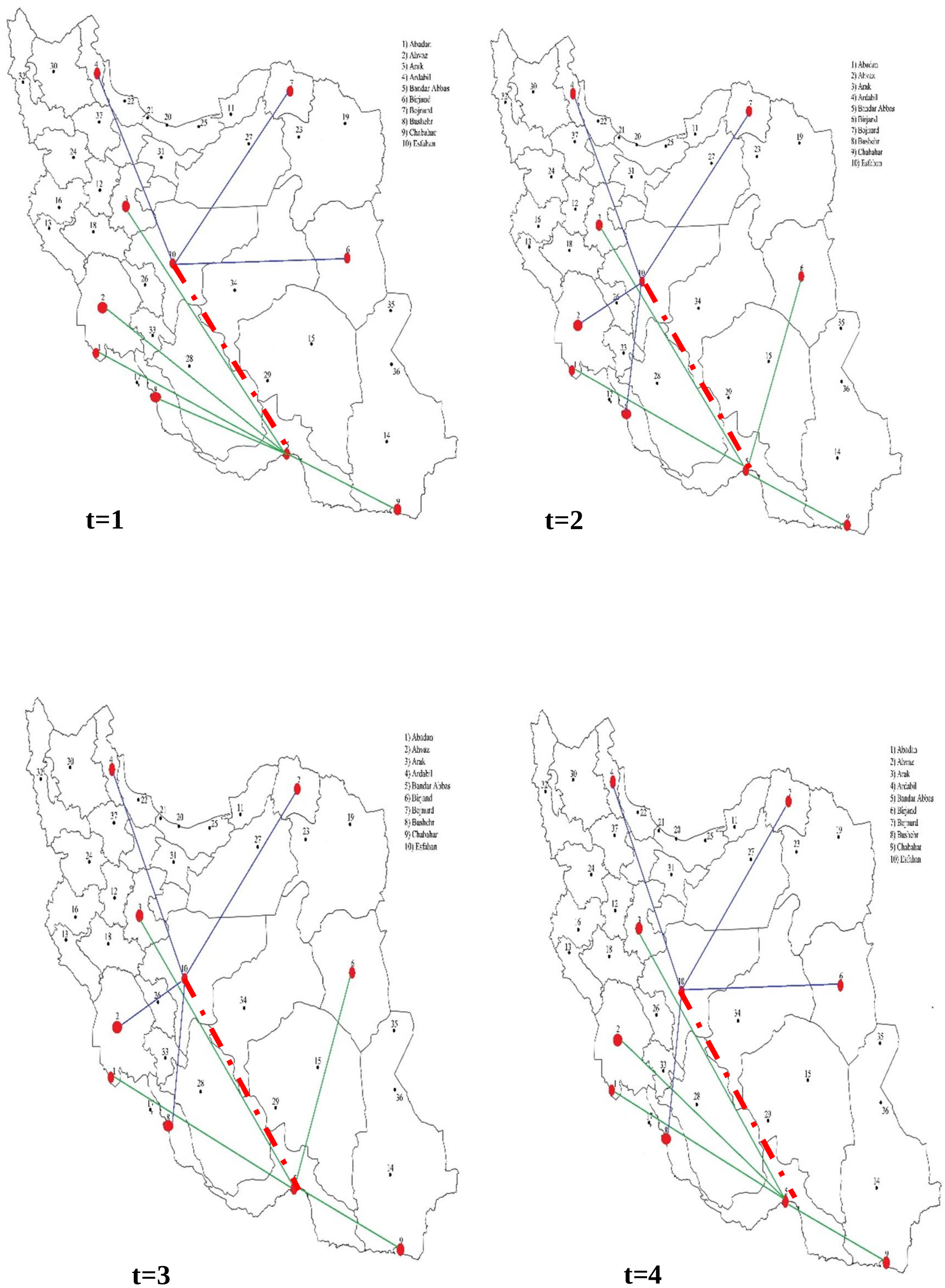

Fig. 2. Hubs locating and assigning non-hubs nodes to hubs

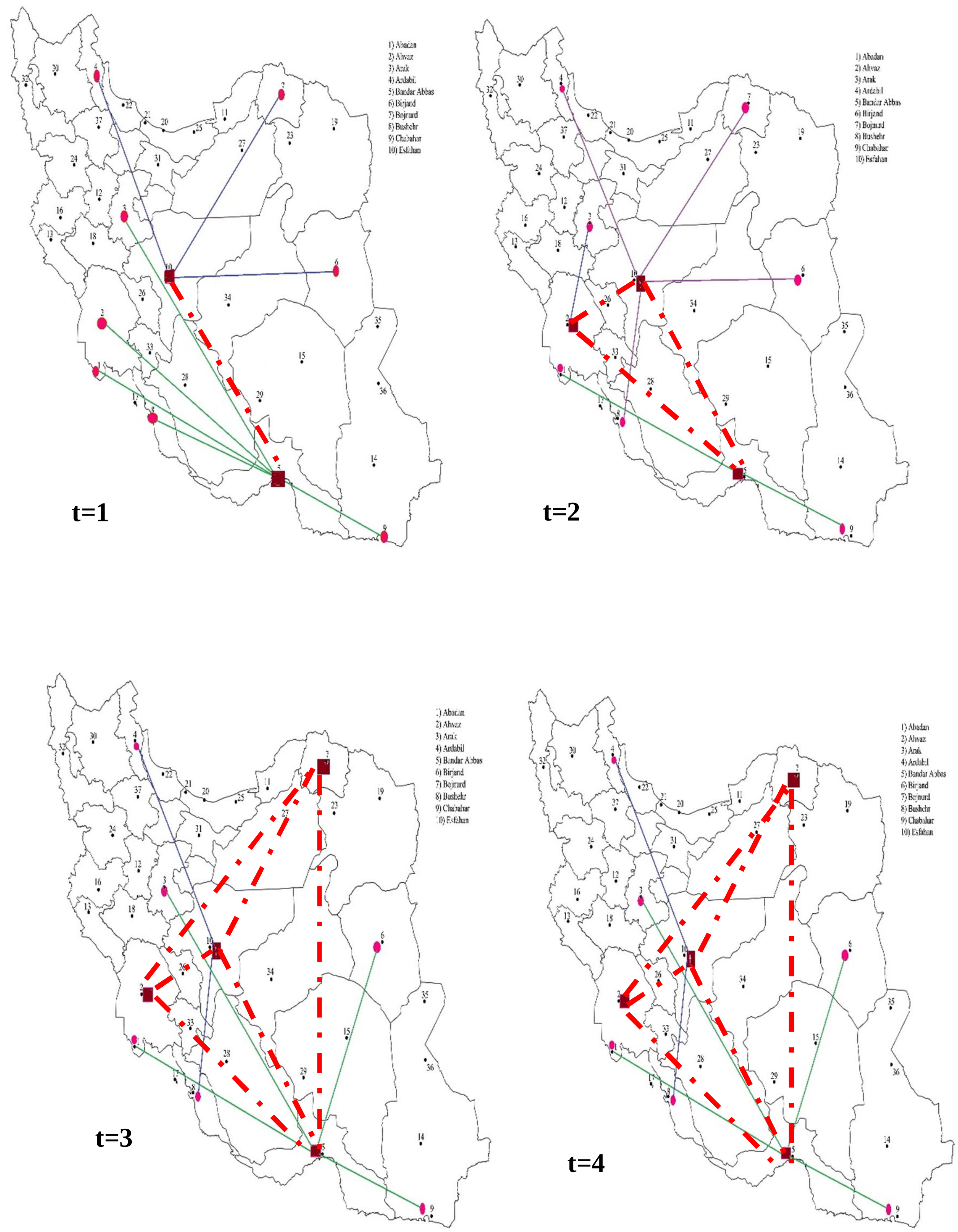

Fig. 3. Hubs locating and assigning non-light nodes to hubs by converting limitation 3 to equality

To evaluate the model, some of the important factors have been investigated. These factors include the discount factor of two hubs, a discount factor of movement between nodes and hub, the number of penalties associated with the flow congestion, and the effective capacity of the hubs. In Table 4, in each row, the value of the objective function is shown by changing the corresponding coefficients.

Tab. 4. Sensitivity analysis of important parameters

Percent increase	α	β	e(t)	U(k)
-%40	1.939	1.456	2.129	2.12901
-%20	2.036	1.793	2.12871	2.12886
0	2.129	2.129	2.129	2.129
+%20	2.219	2.462	2.12869	2.12856
+%40	2.308	2.793	2.12871	2.1284

As shown in Figure 4, reducing the discount factor (increasing moving cost) increases the amount of objective function and increasing the amount of discounts reduces the objective function. Given that the moving discount coefficient between nodes and hubs is calculated twice in the objective function, it increases the objective function further. Therefore, changes in the slope of the objective function are faster with variations of β.

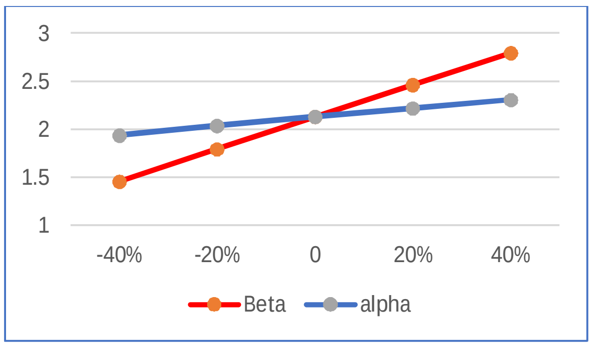

Fig. 4. Sensitivity analysis of α and β parameters

According to Table 4, the congestion penalty and the hubs' effective capacity also change. Since the model attempts to not impose a penalty on capacity overload, the change slope will be very slow. This factor is shown in Figure 5.

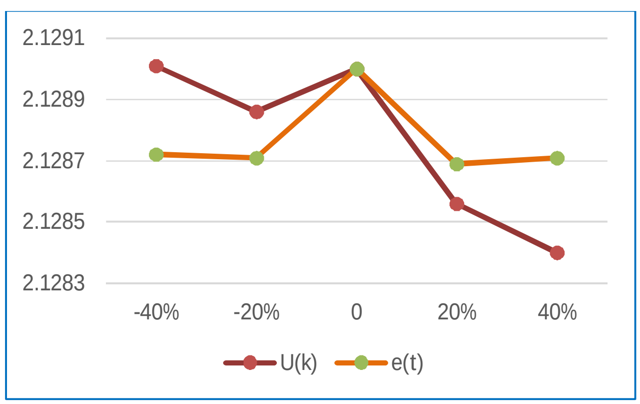

Fig. 5. Sensitivity analysis of the flow penalty and capacity of the hub

4. Conclusion

In this paper, the new dynamic hub location model was introduced with respect to the reliability and flow congestion effects. This possibility was given to create or close hub facilities according to different conditions. The reliability factor was also used to increase the safety factor for transportation, and maximizing the minimum reliability was targeted. Due to the high flow congestion of hubs, an attempt was made to reduce the input volume to the hub by considering congestion penalty; then, the flow was distributed across the hubs proportionally. The model is non-linear and bi-objective that was solved after linearization with ε-constraint method. One way to extend this model is the combination of location and routing with regard to traffic volume. Another suggestion is importing the loading and unloading schedules in the hubs, which will be important for the arrival time of vehicles and the queue created by them. The model also has the ability to implement with more nodes using meta-heuristic algorithms to achieve desirable results in a short span of time.

References

[1] Zarandi, MH Fazel, S. Davari, and SA Haddad Sisakht. The Q-coverage multiple allocation hub covering problem with mandatory dispersion. *Scientia Iranica* Vol. 19, No. 3, (2012), pp. 902-911.

[2] Ernst AT, Krishnamoorthy M. Efficient algorithms for the uncapacitated single allocation p-hub median problem. *Location Science*, Vol. 4, No. 3, (1996), pp. 139-54.

[3] Ernst, Andreas T., and Mohan Krishnamoorthy. An exact solution approach based on shortest-paths for p-hub median problems. *INFORMS Journal on Computing*, Vol. 10, No. 2, (1998), pp. 149-162.

[4] O'Kelly ME. A quadratic integer program for the location of interacting hub facilities. *European Journal of Operational Research*, No. 32, (1987), pp. 393-404.

[5] Ernst, Andreas T., and Mohan Krishnamoorthy. Exact and heuristic algorithms for the uncapacitated multiple allocation p-hub median problem. *European Journal of Operational Research*. Vol. 104. No. 1, (1988), pp. 100-112.

[6] O'Kelly ME, Miller HJ. Solution strategies for the single facility minimax hub location problem. *Papers in Regional Science*, Vol. 70, No. 4, (1991), pp. 367-80.

[7] Klincewicz JG. Heuristics for the p-hub location problem. *European Journal of Operational Research*, No. 53, (1991), pp. 25-37.

[8] Skorin-Kapov D, Skorin-Kapov J, O'Kelly ME. Tight linear programming relaxations of uncapacitated p-hub median problems. *European Journal of Operational Research*, No. 94, (1996), pp. 582-93.

[9] Ebery J, Krishnamoorthy M, Ernst AT, Boland N. The capacitated multiple allocation hub location problem: formulations and algorithms. *European Journal of Operational Research*, No. 120, (2000), pp. 614-31.

[10] Ernst AT, Krishnamoorthy M. Solution algorithms for the capacitated single allocation hub location problem. *Annals of Operations Research*, No. 86, (1999), pp. 141-59.

[11] Aykin T. Lagrangean relaxation based approaches to capacitated hub-and-spoke network design problems. *European Journal of Operational Research*, No. 79, (1994), pp. 501-23.

[12] Campbell, James F., and Morton E. O'Kelly. Twenty-five years of hub location research. *Transportation Science*, Vol. 46, No. 2, (2012), pp. 153-169.

[13] O'kelly, Morton E. The location of interacting hub facilities. *Transportation science*, Vol. 20, No. 2, (1986), pp. 92-106.

[14] Contreras, Ivan, Jean-François Cordeau, and Gilbert Laporte. The dynamic uncapacitated hub location problem. *Transportation Science*, Vol. 45, No. 1, (2011), pp. 18-32.

[15] S. Gelareh, S. Nickel, and D. Pisinger. Liner shipping hub network design in a competitive environment. *Transpo Res. Part E Logist. Transp. Rev.*, Vol. 46, No. 6, (2010), pp. 991-1004.

[16] A. Makui, M. Rostami, E. Jahani, and A. Nikui, A multi-objective robust optimization model for the capacitated P-hub location problem under uncertainty. *Manag. Sci. Lett.*, Vol. 2, No. 2, (2012), pp. 525-534.

[17] Gelareh, Shahin, and Stefan Nickel. Hub location problems in transportation networks. *Transportation Research Part E: Logistics and Transportation Review*, Vol. 47, No. 6, (2011), pp. 1092-1111.

[18] Taghipourian, Farzin, et al. A fuzzy programming approach for dynamic virtual hub location problem. *Applied Mathematical Modelling*, Vol. 36, No. 7, (2012), pp. 3257-3270.

[19] Eghbali, Maryam, Mostafa Abedzadeh, and Mostafa Setak. Multi-objective reliable hub covering location considering customer convenience using NSGA-II. *International Journal of System Assurance Engineering and Management*, Vol. 5, No. 3, (2014), pp. 450-460.

[20] Ghodratnama, A., Tavakkoli-Moghaddam, R. and Azaron, A. A stochastic approach for a novel p-hub location-allocation problem with opening and reopening modes. *International Journal of Business Performance and Supply Chain Modelling*, Vol. 7, No. 4, (2015), pp. 305-337.

[21] Gelareh, S. Neamatian Monemi R. and Stefan Nickel. Multi-period hub location problems in transportation. *Transportation Research Part E: Logistics and Transportation Review*, No. 75, (2015), pp. 67-94.

[22] Yang, Ta-Hui, and Tzu-Yu Chiu. Airline hub-and-spoke system design under stochastic demand and hub congestion. *Journal of Industrial and Production Engineering*, Vol. 33, No. 2, (2016), pp. 69-76.

[23] Bashiri, Mahdi, et al. Mathematical modeling for a p-mobile hub location problem in a dynamic environment by a genetic algorithm. *Applied Mathematical Modelling*, No. 54, (2018), pp. 151-169.

[24] Steuer, R. E. Multiple criteria optimization.Theory, computation and application (2nd ed.). London: Wiley. (1986).

[25] Miettinen, K. M. Nonlinear multiobjective optimization. *Boston: Kluwer Academic Publishers*. (1998).

[26] Mavrotas, G. Effective implementation of the ε constraint method in multi-objective mathematical programming problems. *Applied Mathematics and Computation*, Vol. 213, No. 2, (2009), pp. 455-465.

[27] Karimi, H., and M. Bashiri. Hub covering location problems with different coverage types. *Scientia Iranica*, Vol. 18, No. 6, (2011), pp. 1571-1578.

[28] Hwang, C.L. and Yoon, K., Multiple Attributes Decision Making Methods and Applications, *Berlin: Springer* (1981).

[29] Benitez, J.M., Martin, J.C. and Roman, C. Using fuzzy number for measuring quality of service in the hotelindustry, *Tourism Management*, Vol. 28, No. 2, (2007), pp. 544-555.

[30] Roghanian, E., and Shakeri Kebria, Z. The combination of topsis method and Dijkstra's algorithm in multi-attribute routing. *Scientia Iranica*, Vol. 24, No. 5, (2017), pp. 2540-2549.

Follow This Article at The Following Site:

Fattahi P, Shakeri Kebria Z. A Bi- objective dynamic reliable hub location problem with congestion effects. IJIEPR. 2020; 31 (1) :63-74
URL: http://ijiepr.iust.ac.ir/article-1-1019-en.html