Journal of Industrial and Systems Engineering
Vol. 9, special issue on location allocation and hub modeling, pp 1-22
Winter (February) 2016

Hierarchical Facility Location and Hub Network Problems: A literature review

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Abstract

This paper presents a complete review of published researches about hierarchical facility location and hub network problems. In hierarchical network facilities with different service levels, we are with a top-down or down-top manner interaction. In Hierarchical systems, service levels are composed of different facilities. In this paper, published papers from 1970 to 2015 are studied and a comprehensively classification is presented. Mathematical models are classified based on different properties such as: input, output, objective functions, constraints, applications, some of the real world case studies and solution methods. Finally, according to proposed classification, conclusion and future research to tackle real world hierarchical facility location problems and hierarchical hub network problems is presented. This study can be used as a comprehensive reference in the hierarchical facility location problems, particularly those based on hub networks.

Keywords: Hub and Spoke, hierarchical facility location (HFLPs), hierarchical hub network problems (HHNPs), review paper.

1- Introduction

In a hierarchical system, facilities are interrelated in a top-down or bottom-up manner at various levels of services. There are N composed levels of services, the lower and the higher levels are entitled as "the first level" and the "N th level". Customer sites and demand nodes are assigned to level 0. The structure of hierarchical facility location problem is considered as a network. The purpose of this study is to find the optimum location of facilities in each level of services and to determine the closest service levels between the demand location and facilities. The hierarchical location problem could be categorized based on available amount of budget, the location of facility in each level of services and customer assignments to each level of hierarchy (Narula (1986) and Sahin and Sural (2007)).

Hubs are special concentrators which are designed to act as switching, transshipment and sorting points in distribution, transportation, telecommunication systems and etc. Hubs concentrate flows in order to take advantage of economies of scale, instead of sending flows directly between all origin–destination pairs (Alumur and Kara (2008) and Gelareh and Nickel (2011)). In the last two decades, hub network design problems have been focused on many fields of application areas such as telecommunications, transportation, computer networks, postal services and supply chain management (Sahin and Sural (2007) and Gelareh and Nickel (2011)).

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ISSN: 1735-8272,

The main assumption of hub location problems is that the direct connection between origin and destinations (demands nodes) are not allowed. In other words, in order to achieve the destination, the flow will be transmitted through the shortest path of one or multiple hubs. In summary, the goal of hub location network is: (1) hub selection, the number of nodes considered as hub nodes and (2) the assigning of non-hub nodes to hub nodes (Meyer et al. (2009)).

Hub allocation is classified in two categories: (1) single allocation (SA) and (2) multiple-allocation (MA). In single allocation each demand nodes can assign to one hub node and in a multiple-allocation, spoke nodes (customer) can be connected to one or more hub nodes (Meyer et al. (2009)).

However, the most significant issue in transportation systems, logistics networks and communications is the flow of demand between origins and destinations. The concept of hub network design problem is considered when the amount of flow transmitted between origin and destination while simultaneously using all the existing nodes of direct communication is expensive or not feasible (Farahani and Hekmatfar (2009)).

2- Classification of hierarchical problems

Hierarchical facility location problems and hierarchical hub network problems are classified according to four attributes as following (Sahin and Sural (2007)):

[1] Flow pattern
[2] Service varieties
[3] Spatial configuration
[4] Objectives

In order to design an efficient network based on the case study and applications for each organization, four mentioned attributed should be investigated and determined. The characteristics and classifications of each attribute are studied in the following:

2-1- Flow patterns

Different characteristics of flow patterns could define the commodity or services flow discipline between levels of services in a network. According to Sahin and Sural (2007) the flow pattern is categorized in two classifications such as: Single-flow and Multi-flow.

2-1-1- Single flow

In single flow, the customers and/or commodities flow is started from service level 0 and ended according to the priority levels of facilities at the highest level, vice versa. In other words, to achieve the highest levels, customers should pass the lower ones (Sahin and Sural (2007)).

2-1-2- Multi flow

In multiple-flow, the respect to demand satisfaction is possible from any of the a lower or higher levels and it could end to any of the b lower or higher levels($a, b \in \{0,1,...,N\}$). In other words, customers of any level could pass directly the specific levels of services. Location decisions of multi-flow systems are more complex. The main difference between multi flow and single-flow is that there are several specific and different paths to satisfy the demand in each location (Narula and Ogbu (1985) and Sahin and Sural (2007)).

2-2- Service availability

Service varieties is another attribute that must be considered in the hierarchical facility location problems, in which every system is categorized as nested or non-nested system based on the service availability in each levels of hierarchy (Sahin and Sural (2007)).

2-2-1- Non nested hierarchy or non specified hierarchy

In a non nested hierarchy all the services of the lower levels with some different additional services existed and provided in a higher levels facility. In other words, the services of each level are contained of the specific and additional services from lower levels (e.g. in health care systems). The multiple-flow is one of the main attributes of nested hierarchy, since all the services in lower level are offered in the highest level (Sahin and Sural (2007)).

2-2-2- Nested hierarchy

According to a nested hierarchy, different sets of services are provided in each service level. There are distinct services in each level and the customer doesn't get service by higher level without the permission and passing of the lower levels. This has been defined as single flow but without coherence, e.g. in education systems (Sahin and Sural (2007)).

2-3- Spatial configuration

The configuration between N level of services in hierarchical facility location problems are classified to coherent and non-coherent spatial and will be discussed about in two categories as following:

2-3-1- Coherent system

Each demand can only receive services from a single hierarchy. The service route is also assigned to one hierarchy (Sahin and Sural (2007)).

2-3-2- Non coherent system

In the non-coherent systems, it's possible that facilities of lower levels to be assigned to different facilities of higher levels. In other words, each demand node can be served by different levels of hierarchy and a facility of a lower service level could refer the customer (a demand node) to a facility of a higher level outside the hierarchy (Sahin and Sural (2007)).

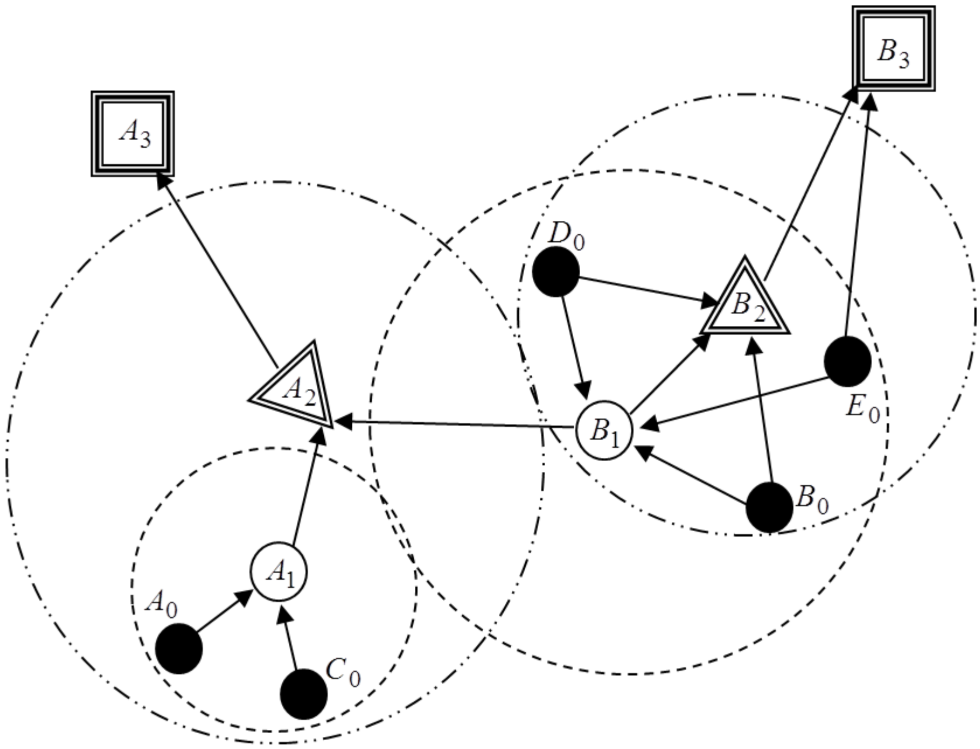

Fig.1. Hierarchical network with three levels of services and two different flow pattern (Sahin and Sural (2007))

Figure (1) shows a network with two different flow patterns such as: single-flow and multi-flow with three levels of services. Services in different levels are shown with different shapes. First level of services is shown by white circle, second level by rectangular, third level by square; also the black circles are demand nodes. For example (B0) can start with both (B1) and (B2) at the same time to have their services done so the flow pattern is considered a multi-flow. Medical services have this flow pattern. (A0) and (C0) can take services beginning with (A1) and then sequentially have (A2) and (A3) but it's not allowed to start with (A2) and (A3). The flow pattern is considered a single-flow. Education systems mostly have this flow pattern. According to definitions presented in the hierarchical facility location problems, (B0), (D0) and (E0), have a three level hierarchy, multiple flow, nested and incoherent structure. (A0) and (C0) represent a three level hierarchy, single flow, non-nested and coherent structure.

2-4- Objectives

The types of objectives to locate facilities are classified in three main categories as follows (Sahin and Sural (2007)):

2-4-1- Median models

The purpose of these models is to minimize the demand weighted total distance (transportation cost) between customers and facilities. In other words the main objective is to locate the new facilities in a way that their distance from the existing ones would be equal.

The advantages are quantifying sum of distances (costs), focused on graph theory, predetermine the number of facilities and find the median points among the public services (candidate points) including schools, hospitals, fire stations, Ambulance, technical audit stations of cars and etc.(Daskin and Maass (2015) and Farahani and Hekmatfar (2009)).

2-4-2- Covering models

In this model, if a facility is located in a particular cover radius, a customer will be covered by a facility. The main covering objectives divided in two categories: (1) set covering; objective is to minimize the number of facilities required to cover all the customers. (2) Maximum covering; objective is to maximize the customers that are covered by the specific number of facility.

The advantage of this model is being present at a place in the shortest time, and assigning each center to respond to an event or emergency situations based on the density of each location and coverage radius and attention to the service quality (Garcia and Marin (2015)).

2-4-3- Fixed charge location models

The objective is to minimize the costs of establishing the facilities and transportation. Hence, the hierarchical location problem could be considered as a location -allocation problem.

The problem determines the number of facilities and where to establish the facilities to satisfy the demand (Fernández and Landete(2015).

The median, coverage and fixed charge location models are the NP-Hard problems, hence finding the best solution for the larger sizes of this model needs more time and is more complicated (Daskin and Maass (2015), Farahani and Hekmatfar (2009)).

In Figure (2) papers since 1970 till now, have been classified based on four main attributes such as flow pattern, service varieties, spatial configuration and objectives.

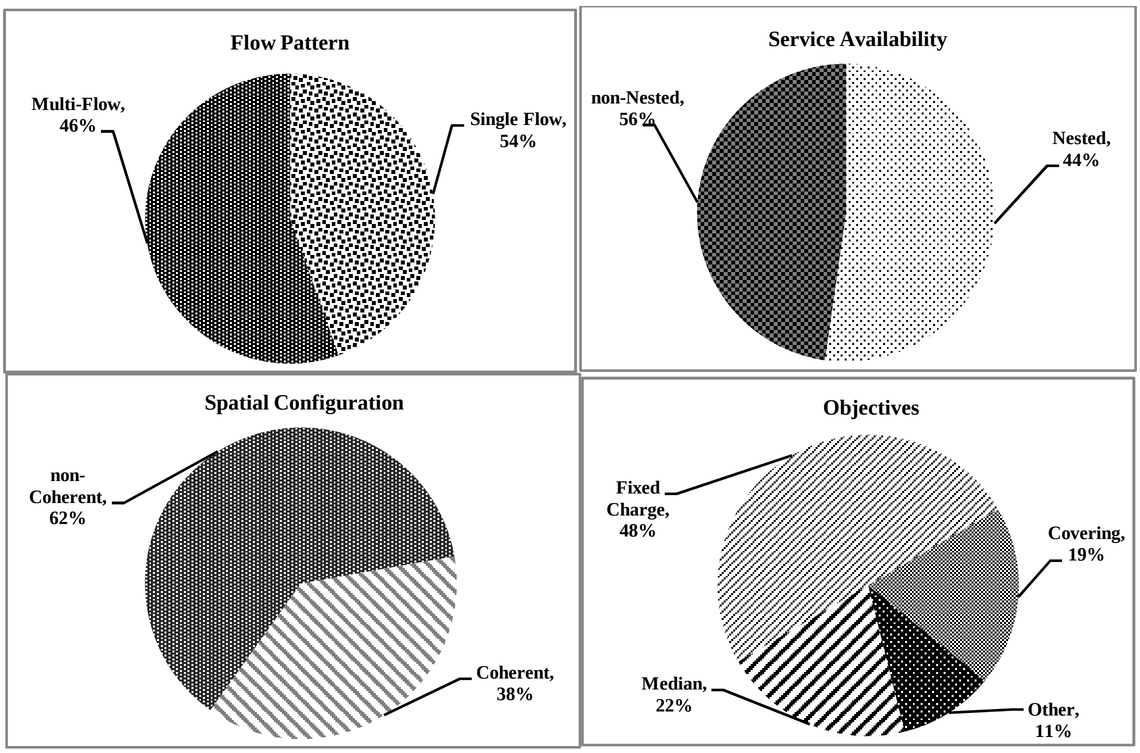

Fig.2. Frequency percentage based on flow pattern, service availability, spatial configuration and objectives (100papers)

3- Basic hierarchical facility location problems (HFLPs) and hierarchical hub network problems (HHNPs)

Hierarchical facility location problem researches' are divided in two categories. Most of these papers have been used in different scope and few numbers of them have used Hub-and spoke network in their models. So we will classify the papers of location problems in two general groups: (1) Hierarchical facility location problems (HFLPs), (2) Hierarchical hub network problems (HHNPs).

3-1- Hierarchical facility location problems (HFLPs)

Schultz (1970) and Calvo and Marks (1973) were the first to study hierarchical facility location within a multiple layer configuration. The first researches of hierarchical location problems were discussed in 80s (Narula (1986)). Dokmeci (1973) studied the hierarchical location problem to find the best location and scale of facilities, by representing a three level algorithm solution.

Geoffrion (1980), Moore and Revelle (1982), Narula (1986), Chung et al. (1992), Narasimhan et al. (1992), Jayarmanin et al. (2003) and Gupta et al. (2003) developed the heuristic approaches to solve the hierarchical facility location problem and hierarchical hub network problem models.

Narulaans Ogbu(1979) tried to present a health service system with two levels of services (health center and hospital) to achieve the minimum travel distance. Serra et al. (1992) studied the maximum – capture hierarchical facility location problem with three levels of services. They considered the location of new facilities as well as the relocation of existing facilities.

Jayarmanet al. (2003) worked on hierarchical service facilities model for the location-allocation with several layers of services. The paper developed an integer linear programming model, also a Lagrangian relaxation methodology coupled with a heuristic approach is used.

Also Espejoet al. (2003) developed 2-level hierarchical problems proposed by Moore and ReVelle (1982). They defined a combined Lagrangean–surrogate (L–S) relaxation method which reduces to a 0–1 knapsack problem and compared their solution to exact results obtained using CPLEX.

Ageev et al. (2004) studied a hierarchical location problem and then improved combinatorial approximation algorithm for a k-level facility location problem. Sun et al. (2004) worked on a developing two level of fast hierarchical facility location problem model for video on demand (VoD) server deployment to minimize the per link cost between origin and destination and cache/central server costs.

Horner et al. (2005) studied hierarchical assignment problem to optimize the spatial flow pattern between individual origin and destination locations. The objective function is minimizing the total assignment costs of matching agents with tasks.

Johnson et al. (2005) studied a three-level hierarchical location of service facilities for the elderly. Objective minimizes consumer disutility and unserved demands and maximizes the total number of demands for all types of services that are provided. According to the increase in their population in societies, presenting a variety of supportive services for elderly adults is necessary and is well-done in this research.

In health service models, limited capacity of service facilities is natural. Hence the weight of load distributed among the existing facilities is an important part of every network. Galvaoet al. (2006) in a three-level hierarchical facility location studied the load balancing to minimize distance travel; also to solve the model a heuristic Lagrangian approach was developed.

Kantor and Peleg(2006) developed a heuristic algorithm in a k-level hierarchical model to minimize costs of location and allocation, and then Kantor and Peleg(2009)worked on presenting better approaches to develop heuristic algorithms.

Shavandi and Mahlooji(2007) used queuing theory for fuzzy hierarchical location-allocation models, which are developed for the maximal covering location problem (MCLP) with low and high levels.

Sahinet al. (2007) in another research, studied the Hub network problem of Turkish Red Crescent (TRC) blood services to improve quality of them; using two levels of services: regional bloods centers (upper-level) and the blood centers, blood stations, and mobile units (lower-level).

Yasenovskiy and Hodgson (2007) worked on three-level healthcare facilities. Level 1 (low), Local health center, Including first aid and preventive emergency services, Level 2 (mid), Community health center, which along serving first level services ,does some therapeutic procedures too, Level 3 (high): Medical center which along serving both level 1 and level 2 duties presents specialized and curative services as well.

Some of review papers on hierarchical facility problems (Narula(1986) and Sahin and Sural(2007)) used "hierarchy" title as a name of concentrators for several types of facilities in multi-level systems. In another review paper, classifications and surveys network hub location models are presented (Alumur and Kara (2008)).

Ignacio et al. (2008) studied how to connect terminals to the concentrators and connect them to routers in two-level hierarchical location problem in computer networks. The main purpose was to determine numbers of concentrators and routers, where they should be located and which users (concentrators) assign to each concentrator (routers). A Lagrangian relaxation method is used to define lower bound, and then a tabu search metaheuristic algorithm is developed. The hierarchical location for public facilities planning in a discrete space with main features like: several levels of demand and facilities, a nested hierarchy of facilities, capacity constraints, single assignment and closest assignment constraints called path assignment constraints considered by Teixeira and Antunes(2008) with the purpose of maximizing accessibility.

Ratick et al. (2009) presented the hierarchical maximal covering model to the location of medical facilities with High Level (hospital) and Low Level (clinics) in the Kohat district in Pakistan, introduced by Moore and Revelle (1982).

Lee and Lee (2010) studied a hierarchical facility location problem considering both full and partial coverage ratio. The main objective function of proposed model is to attend which facility should be open and customers should be covered by which kind of services. A heuristic approach based on a tabu search (TS) is also developed.

Wang et al. (2010) presented an approximate algorithm for stochastic hierarchical facility location model considering different scenarios to minimized costs of shipping and assigning client to path. Bigotte et al. (2010) studied an integrated modeling of urban hierarchy with several levels and transportation network. The objective function minimized the travel time and redesigned the network to maximize the accessibility to facilities by heuristic methods.

Cinar and Yaman (2011) investigated the vendor location problem (VLP) considering two levels of hierarchy. The numbers and capacity of vehicle transportation are limited. Drexl (2011) studied concentrator location problem considering K levels of hierarchy to assign the closest facility and Costa et al. (2011) presented a two-level network design with intermediate facilities (electrical distribution network) to minimize costs of the network considering capacitated vertex facility. Then proposed a hybrid decomposition approach and used branch-and-cut methods to limit the computational burden.

Sheu and Lin (2012) presented a new model of hierarchical facility network planning for global logistics (GLs) network with considered potential risk-oriented costs in three levels of services. This method, which is based on the hierarchical cluster analysis, determines the same locations, numbers, service areas and facilities in logistic network, by maximizing operational benefits and the customer satisfaction rate, minimizing network configuration costs.

Addis et al. (2013) studied a single source capacitated facility location problem with intermediate level and upper level facilities. All the communications in the network, such as connections between level 1 and 2, and also customer allocation to level 1 should be optimized. For solving the proposed model a heuristic approach based on very large scale neighborhood search has been used and compared to exact method.

In (2014), Farahani et al. presented a model for a hierarchical maximal covering location problem by considering the risk of disruptions for different levels of facilities. In real world, for some reasons such as congestion, earthquakes, floods and adverse weather conditions facilities lose their efficiency and disturb the whole network therefore considering the risks of disruptions and reliability in network is absolutely needed. In order to solve the proposed model developed a hybrid artificial bee colony (HABC) algorithm.

Farahani et al. (2014) investigated the hierarchical facility location models in a review paper, also classified the published papers till (2012) to four general categories and presented application and solution method for them. Aliakbarian et al. (2015) developed a bi-level (leader-follower) hierarchical model under imminent attacks to minimize the maximum total weighted traveled distance by customers to receive their corresponding services.

3-2- Hierarchical hub network problems (HHNPs)

Basically, the first dynamic location problem was presented by Flynn and Ratick (1988) to develop an aiding approach for decision makers to allocate potential points in an Essential air service (EAS). They studied multi-objective maximal covering hub network problem with k level of hierarchy to minimize the costs. Also Shaw (1993), Shmoys (1998) and Sarkis and Sundarraj (2002) studied hierarchical hub network problems.

Lin and Chen (2004) investigated hierarchical hub network problem with single allocation for time-definite with common carriers to the total operating cost. Kijmanawat and Ieda (2005) developed an approach that can solve single allocation and multilevel hierarchical hub network design problem. In this model in order to divide a network to several small clusters with manageable numbers of nodes, clustering algorithm has been used. Each cluster is solved by using hybrid heuristic algorithm based on genetic algorithm (GA) and tabu search (TS).

Thomadsen et al. (2007) the hub location problems with two levels interconnected models of determining the access networks and the backbone network with multi-commodity in discrete space is studied. In order to solve the models, column generation methods is developed. Lin and Chen (2008) studied generalized hub network problems which have capacitated and directed networks configuration. In fact hub network planning problems were determined regarding to shipping paths in order to minimize the operating costs.

Hierarchical hub median location problem considering a certain multi-commodity and single objective model in a discrete space where the network consist of three layered such as central hubs in top level and hub nodes in second and third levels, was initially introduced by Yaman (2009).

Miranda et al. (2009) presented a single objective e-Work based on collaborative optimization for logistic network problem with multi-levels of services where parameters are uncertain and scenario based. Yuet al. (2009) studied hierarchical model which was based on clustering, for urban transit hub location planning. In fact this model is developed to choose the best location and size of facilities in urban transit hub with the objective of minimizing demand-weighted total travel time.

Chen (2010) presented a heuristic approach to solve hierarchical hub network of time-definite common carrier operation planning problem and worked on determining the types of the vehicle and also associated routing and scheduling simultaneously, by using tabu Search (TS) algorithm.

Lin (2010) studied integrated secondary route network design model in the hierarchical hub networks for dual express services to minimizing service time and operations restrictions and formulate an integer mathematical model. In hierarchical hub network each center is connected by a secondary path while hubs are connected to each other by primary.

Sahraeian and Korani (2010) studied hierarchical hub maximal covering problem with restricted cover radiuses and three levels of services. In network, at first level, there are central hubs, in second level hubs are connected to central hubs and in third level demand centers are connected to hubs or central hubs.

Contreras et al. (2010) investigated hub location problem when a number of hubs are fixed and the hubs are connected to each other in tree-star network. Applications of proposed model are in telecommunication and transportation systems, when set up costs of connection between non-hub nodes are so high.

Chi et al. (2011) studied the connection between sudden disasters and humanitarian relief. Though there are complex reasons that make it difficult to coordinate organizations with relief and decrease the responsibility and efficiency.

Ayed (2011) introduced an operational single-objective parcel distribution network design in discrete space with deterministic parameters and Sender and Clausen (2011) worked on a new hub location model to design the network of wagonload traffic by using multiple levels of services considering the discrete solution space and also minimizing operational and transportation costs.

Alumur et al. (2012) considered covering problem with single objective in discrete space as the hierarchical multimodal hub location problem with time-definite deliveries (HMHL-TDD). Presented model includes 4 layers as: demand nodes in level zero, non-central hubs in level one, median non-central hub in level 2 and eventually in the last level, central hub.

Davari and Zarandi (2012) studied hierarchical hub median location problem with fuzzy demand, single commodity and single allocation in three levels of services (demand nodes, non-central hubs, and central hubs). The structure of the model is derived from Yaman (2009). In this research it is assumed that demands are not exactly known and are estimated by fuzzy variables. In order to solve the problem variable neighborhood search (VNS) and CPLEX approaches have been used.

Yaman and Ellomi (2012) investigated hub location problems in three levels with star network connection and bounded path length, in other words P hubs are selected and connected to central hub with direct connection and the non-hub node is connected to a hub node. This results in a star/star network.

Saboury et al. (2013)has considered three-level hierarchical networks with fully interconnected backbone and access networks. In this problem, there is a specific application of hub location, which is known as problem of fully interconnected networks planning.

Martins de sa et al. (2013) studied the tree of hubs location problem by improving Benders' decomposition algorithm. In location problems, the tree of hubs location network is one of the most difficult problems and in order to solve it by bender's decomposition algorithm, there would be some difficulties for having both optimum and feasible solution at the same time.

In a review paper, Farahani et al. investigated basic hub location models till (2013), sorted them to 13 general categories and studied solution algorithms of hub location problems and their applications.

Rieck et al. (2014) presented many-to-many location-routing model with 3 level hierarchy and multi-commodity pickup-and-delivery. The levels are delivery points, potential hubs and supply points and the objective is minimizing fixed depots and operating and transportation costs. In order to solve the proposed model genetic algorithm (GA) method is introduced.

Rodrigues-Martin et al. (2014) studied the hub location and routing problem model to minimize the costs of transportation and routing through two hierarchical levels. The non-hub nodes are assigned to hub nodes on a cycle. Decisions are about the optimum location of hubs and assigning the non-hub nodes to hub nodes and routing the traffic, also using Branch and cut algorithm, which is proposed to solve and tested on CAB and AP instances from the literature.

Hierarchical hub location problem was introduced by Yaman (2009) considering the second type of coverage and mandatory dispersion of central hubs in order to provide high service level for a competitive environment presented by Rajabi and Avakh Darestani (2015).

Fazel Zarandiet al. (2015) developed two metaheuristics, Simulated Annealing (SA) and Iterated Local Search (ILS), and compares their performances for the hierarchical single allocation hub median location problem. Shahanaghi et al. (2015) studied a capacitated three level hierarchical p-hub median problem considering the penalty costs of lateness in delivery time to minimize total costs.

It could be expected that there are still research gaps in the current literature. In fact it could be considered that the distance from customer and resources and the place, caused by physical, social and political conditions are rarely studied in the current literature. Also the risks related to nature and the human beings were not investigated in proposed models. It is clear that minimizing the costs of risks are the main subject that should be more attended, so costs of deal and managing the disasters such as congestion, earthquakes, floods and adverse weather conditions could also help developing the relevant models. Moreover, considering the deterministic parameters in the proposed models, causes getting away from the essence of real world.

3-3- Classification of published papers in HFLPs and HHNPs

In this review paper, hierarchical facility location problems and hierarchical hub network problems till 1970 have been studied. Published models of hierarchical location problems and hierarchical hub network problems are sorted based on their years of publication in order to demonstrate the trend of evolution. This paper has classified all the researches of hierarchical facility location problems and hierarchical hub network problems based on multiple characteristics including inputs, outputs, objective functions, constraints and applications in Table (2) with regard to modeling attributes in Table (1).

Table 1. Characteristics used for classification of the published models

Objective Functions (Min and Max)	FC	Fixed Cost	**Number of Objectives**	SO	Single Objective
	TC	Transportation Cost		MO	Multi-Objective
	OC	Operational Cost	**Parameters or Models**	Det	Deterministic
	IHC	Inventory Holding Cost		Pro	Probabilistic
	RouC	Routing Cost		Sto	Stochastic
	SC	Setup Cost		Fuz	Fuzzy
	SeC	Service Cost	**Facilities**	Ex	Exogenous
	TrC	Travel Cost		En	Endogenous
	FrC	Freight Cost	**Flow Pattern**	SF	Single Flow
	UC	User Cost		MF	Multi- Flow
	RC	Risk Cost	**Service Availability**	N	Nested
	PnlC	Penalty Cost		-	Non-Nested
	Di	Distance			
	T	Travel Time	**Spatial Configuration**	C	Coherent
	WTD	Weighted Travel Distance		-	Non-Coherent
	TTD	Total Travel Distance	**Capacity Constraint**	L	Limited
	DWD	Demand-Weighted Distance		U	Unlimited
	NLR	Number of Linkages Required	**Applications**	HC	Health Care Systems
	D	Demand		EMS	Emergency Medical Systems
	P	Profit		ED	Education Systems
	Cov	Coverage		HU	Hub Systems
	SL	Service Level		PD	Production–Distribution Systems
	A	Access (Availability) to Facility		SWM	Solid Waste Management Systems
Time Element	St	Static		TN	Telecommunications Networks
	Dy	Dynamic		Oth	Other Systems

Table 2. Summary characteristics of the HFLPs and HHNPs modeling efforts

Author's (Year)	Objective Functions		Time Element	Number of Objectives	Parameters or Model	Multi Commodity	Facilities	Flow Pattern	Service Availability	Spatial Configuration	Level of Network	Hub Network	Constraints		Applications
	Min	Max											Budget	Capacity	
Schultz (1970)[92]	TrC, SeC	P	St	MO	Det	-	Ex	MF	-	C,-	3	-	✓	U	HC
Calvo and Marks (1973)[15]	Di, T, UC	D	St	MO	Det	-	Ex	SF	-	C,-	3	-	✓	U	HC
Dokmeci (1973)[26]	FC, TC, OC	-	St	SO	Det	-	En	MF	N	-	3	-	-	L	Oth
Geofrion and Graves (1974)[43]	FC, TC	-	St	SO	Det	✓	En	SF	N, -	C, -	2	-	-	L	Oth
Narula and Ogbu (1979)[76]	WTD	-	St	SO	Det	-	En	MF	N	C	2	-	-	L	HC
Charnes and Storbeck (1980)[17]	-	Cov	St	SO, MO	Det	-	En	MF	N	-	2	-	-	U	EMS
Tien et al. (1983)[107]	WTD	-	St	MO	Det	-	Ex	SF	-	C,-	3	-	-	U	HC
Hodgson (1984)[48]	T	SL	St	MO	Det	-	Ex	SF	-	-	3	-	-	U	Oth
Narula (1984)[74]	WTD	-	St	SO	Det	-	Ex	MF	-	-	M	-	-	U	HC
Ro and Tcha (1984)[85]	FC, TC	-	St	SO	Det	-	En	MF	-	-	2	-	-	U	PD
Tcha and Lee (1984)[103]	FC, TC	-	St	SO	Det	-	En	MF	-	-	M	-	-	U	Oth
Tien and El-Tell (1984)[106]	WTD	Cov	St	SO	Det	-	Ex	SF	-	C	2	-	-	U	HC
O'kelly and Storbeck (1985)[78]	T	-	St	SO	Prob	-	Ex	MF	-	-	M	-	-	U	EMS
Hodgson (1986)[49]	T	P	St	SO	Det	-	En	SF	N	-	3	-	-	U	Oth
Flynn and Ratick (1988)[37]	SeC	A, Cov	St	MO	Det	-	Ex	MF	N	C	M	✓	-	U	Oth
Hodgson (1988)[50]	T	P	St	SO	Det	-	Ex	MF	N	C	3	-	-	U	HC
Kirca and Ekip (1988)[59]	FC, OC, TC	-	St	SO	Det	-	Ex	MF	-	-	3	-	✓	L	SWM
Vernekar et al. (1990)[109]	FC, OC	-	St	SO	Det	-	En	SF	-	C	M	-	-	L	TN
Eitan et al. (1991)[28]	FC, TC	-	St	SO	Det	-	Ex	SF, MF	N,-	-	M	-	-	L	Oth
Chung et al. (1992)[20]	FC, TC	-	St	SO	Det	-	En	SF	N	C	3	-	-	U	TN
Gao and Robinson (1992)[40]	FC, TC	-	St	SO	Det	-	Ex	MF	-	C	2	-	-	U	PD
Kim and Tcha (1992)[58]	FC, TC	-	St	SO	Det	✓	En	SF	N	C	2	-	-	U	TN
Narasimhan and Pikul (1992) [73]	SC, TC, OC	-	St	SO	Det	-	En	MF	-	C	3	-	-	L	TN
Serra et al. (1992) [96]	-	Cov	St	SO	Det	-	Ex	MF	N	-	3	-	-	U	Oth

Table 2. Continued

Author's (Year)	Objective Functions		Time Element	Number of Objectives	Parameters or Model	Multi Commodity	Facilities	Flow Pattern	Service Availability	Spatial Configuration	Level of Network	Hub Network	Constraints		Applications
	Min	Max											Budget	Capacity	
Shaw (1993) [99]	NLR	-	St	SO	Det	-	En	MF	-	-	M	✓	-	U	PD
Gerrard and Church (1994) [44]	-	Cov	St	SO	Det	-	Ex	MF	N	-	2	-	-	U	HC
Serra and Revelle (1994) [95]	D	-	St	SO	Det	-	Ex	MF	N	-	3	-	-	U	Oth
Koksalan et al. (1995) [61]	FC, TC, IHC	-	Dy	SO	Det	✓	En	MF	-	-	2	-	✓	L	PD
Aardal et al. (1996) [4]	FC	P	St	SO	Det	✓	Ex	SF	-	-	2	-	-	U	PD
Pirkul and Jayarman (1996) [80]	FC, TC	-	St	SO	Det	✓	Ex	SF	-	-	3	-	-	L	PD
Serra (1996) [94]	-	Cov	St	MO	Det	-	Ex	MF	-	C	2	-	-	U	Oth
Okabe et al. (1997) [79]	TTD	-	St	SO	Det	-	En	MF	N	-	M	-	✓	U	HC
Tragantalerngsak et al. (1997) [108]	FC, TC, OC	-	St	SO	Det	-	En	SF	-	C	2	-	-	L	PD
Aardal (1998) [2]	FC, TC	-	St	SO	Det	✓	En	MF	-	-	2	-	-	L	PD
Alminyana et al. (1998) [9]	D	-	St	SO	Det	-	Ex	SF	N	C	2	-	-	U	Oth
Barros et al. (1998) [12]	FC, TC	-	St	SO	Det	-	En	MF	-	-	2	-	-	L	SWM
Mandell (1998) [66]	-	Cov	St	SO	Prob	-	Ex	MF	N	-	2	-	-	U	EMS
Pirkul and Jayarman (1998) [81]	FC, TC, OC	-	St	SO	Det	✓	Ex	SF	-	-	2	-	-	L	PD
Shmoys et al. (1998) [101]	FC, TC	-	St	SO	Det	✓	En	SF	N, -	C, -	2	✓	-	L, U	HU
Aardal et al. (1999) [3]	SC, FC, TC, SeC	-	St	SO	Det	-	En	SF	-	C	M	-	-	U	Oth
Chardaire et al. (1999) [16]	FC, TC	-	St	SO	Det	-	En	SF	N	C	2	-	-	U	TN
Marin and Pelegin (1999) [68]	FC, TC	-	St	SO	Det	-	En	MF	-	-	2	-	-	L	PD
Guha et al. (2000) [46]	FC, Rouc, SeC	-	St	SO	Det	-	Ex	SF	-	-	M	-	-	L	Oth
Hinojosa et al. (2000) [47]	FC, TC, OC	-	Dy	SO	Det	✓	Ex	SF	-	-	2	-	-	L	PD
Klose (2000) [60]	FC, TC,	-	St	SO	Det	✓	En	SF	-	-	2	-	-	L	PD
Bumb (2001) [14]	FC, TC	P	St	SO	Det	-	En	SF	-	C	2	✓	-	U	HU
Marianov et al. (2001) [67]	FC, OC	Cov	St	SO	Prob	-	Ex, En	SF	N,-	C, -	2	-	-	L	Oth
Ageev (2002) [6]	FC, TC	-	St	SO	Det	-	En	SF	-	C	M	-	-	U	Oth
Galvao et al. (2002) [38]	Di	-	St	SO	Det	-	Ex	MF	N	C	3	-	✓	U	HC
Sarkis and Sundarraj (2002) [91]	TC, FrC	-	St	SO	Det	-	En	MF	N, -	C, -	M	✓	-	U	HU
Espejoa et al. (2003) [29]	-	Cov	St	SO	Det	-	Ex	MF	N	-	2	-	-	U	Oth
Jayaraman et al. (2003) [53]	-	Cov, D	St	SO	Det	-	Ex	MF	N	-	2	-	-	L	Oth
Ageev et al. (2004) [7]	FC, TC	-	St	SO	Det	-	En	SF	-	-	M	-	-	U	Oth
Lin and Chen (2004) [64]	FC, TC, OC	-	St	SO	Det	-	En	MF	N, -	C, -	3	✓	-	L	TN
Sun et al. (2004) [102]	TC, SeC	-	St	SO	Det	-	En	SF	-	C	2	-	-	U	TN
Godor and Magyar (2005) [45]	FC, TC	-	St	SO	Det	-	En	MF	-	-	M	-	-	L	TN
Horner and O'kelly (2005) [51]	TC	-	St	SO	Det	-	Ex	SF	-	-	2	-	✓	U	Oth
Johnson et al. (2005) [54]	Di, TrC, DWD	D	St	SO	Det	-	En	MF	N	-	3	-	✓	L	Oth
Kijmanawat and Ieda (2005) [57]	FC, TC	-	St	SO	Det	-	Ex	SF	N, -	C, -	M	✓	-	U	HU
Galvao et al. (2006) [39]	TTD	-	St	SO	Det	-	Ex	MF	N	-	3	-	✓	L	HC
Kantor and Peleg (2006) [55]	FC, TC	-	St	SO	Det	-	En	SF	-	-	M	-	-	U	Oth
Sahin et al. (2007) [89]	DWD	-	St	SO	Det	-	Ex	MF	N	C	2	-	-	U	EMS
Shavandi and Mahlooji (2007) [98]	-	A, Cov	St	SO	Fuz	-	Ex	MF	N	C, -	2	-	-	L	Oth
Thomadsen and Larsen (2007) [105]	TC	-	St	SO	Det	-	En	MF	N, -	C, -	2	✓	-	L	HU
Yasenovskiy and Hodgson (2007) [113]	DWD	P	St	SO	Det	-	Ex	MF	N	-	3	-	✓	U	HC
Ignacio et al. (2008) [52]	FC, TC, OC	-	St	SO	Det	-	En	SF	-	C	2	-	-	L	TN
Lin and Chen (2008) [65]	FC, OC, TC, IHC, RouC	-	St	SO	Det	✓	En	MF	N, -	C, -	3	✓	-	L	HU
Teixeira and Antunes (2008) [104]	TC	A	St	SO	Det	-	En	SF	-	-	M	-	-	L	ED
Kantor and Peleg (2009) [56]	FC, TC		St	SO	Det	-	En	SF	-	-	M	-	-	L	Oth
Miranda et al. (2009) [71]	FC, TC, IHC	-	St	SO	Prob	✓	Ex	SF	N	-	3	✓	-	L	HU
Ratick et al. (2009) [83]	FC, TC	Cov	St	SO	Det	-	Ex	MF	N	-	2	-	✓	U	HC
Yaman (2009) [111]	TC, RouC	-	St	SO	Det	✓	Ex	SF	N, -	-	3	✓	-	U	HU
Yu et al. (2009) [114]	WTD	-	St	SO	Det	-	Ex	MF	N, -	C, -	2	✓	-	U	HU
Chen (2010) [18]	TC, OC	-	St	SO	Det	-	En	MF	N, -	C, -	3	✓	-	L, U	TN
Contreras et al. (2010) [22]	TC		St	SO	Det	-	Ex	SF	N, -	C, -	2	✓	-	U	HU
Lin (2010)[63]	FC, TC, D	-	St	SO	Det	-	En	MF	N, -	C, -	3	✓	-	L	HU
Sahraeian and Korani (2010)[90]	FC, TC	Cov	St	SO	Det	✓	Ex	SF	N, -	C	3	✓	-	L	HU
Bigotte et al. (2010)[13]	T	A	St	SO	Det	-	En	MF	N	-	M	-	-	L	Oth
Lee J.M and Lee Y.H (2010)[62]	-	Cov	St	SO	Det	-	En	MF	N	-	M	-	-	L	Oth
Wang et al. (2010)[110]	FC, TC		St	SO	Sto	-	Ex	SF	-	-	M	-	-	U	Oth
Ayed (2011)[11]	FC, SC, TC, OC, TrC		St	SO	Det	-	Ex	SF	N, -	C, -	2	✓	-	L	HU
Chi et al. (2011)[19]	FC, TC		St	SO	Det	-	En	SF	N, -	-	2	✓	-	L	HU
Cinar and Yaman (2011)[21]	FC	P, Cov	St	SO	Det	-	Ex	SF	-	C	3	-	-	L	PD
Costa et al. (2011)[23]	FC, TC	-	St	SO	Det	✓	En	SF	-	-	2	-	-	L	TN
Drexl (2011)[27]	FC, TC	-	St	SO	Det	-	En	SF	-	-	M	-	-	L	Oth
Sender and Clausen (2011)[93]	FC, TC		St	SO	Det	-	En	SF	N, -	C, -	3	✓	-	L	HU
Alumur et al. (2012)[10]	FC, TC, RouC		St	SO	Det	✓	Ex	SF	N, -	C, -	2	✓	-	L	HU
Davari and Zarandi (2012)[24]	TC		St	SO	Fuz	-	Ex	SF	N, -	-	3	✓	-	U	HU
Sheu and Lin (2012)[100]	FC, RC	P	St	MO	Det	-	En	SF	N	-	3	-	-	L	Oth
Yaman and Elloumi (2012)[112]	RouC		St	SO	Det	-	Ex	SF	N, -	C, -	2	✓	-	L	HU
Addis et al. (2013)[5]	FC, TC, SC		St	SO	Det	-	En	SF	-	-	2	-	-	L	Oth
Martin de Sá et al. (2013)[69]	FC, TC		St	SO	Det	-	En	SF	N, -	C, -	2	✓	-	U	HU
Saboury et al. (2013)[87]	FC		St	SO	Det	✓	Ex, En	SF	N, -	C, -	3	✓	-	L	HU
Farahani et al. (2014)[30]	-	Cov	St	SO	Det	✓	Ex	MF	-	-	3	-	-	U	HC
Rieck et al. (2014)[84]	FC, TC, OC, RouC	-	St	SO	Det	✓	En	SF	N, -	C, -	3	✓	-	L	HU
Rodriguez Martin et al. (2014)[86]	FC, TC, RouC	-	St	SO	Det	-	Ex	SF	N, -	C, -	2	✓	-	L	HU
Aliakbarian et al. (2015) [8]	MaxWTD	-	St	SO	Det		Ex	MF	N, -	C, -	3	-	✓	U	Oth
FazelZarandi et al. (2015) [35]	RouC	-	St	SO	Det	-	Ex	SF	N, -	-	3	✓	-	U	HU
Rajabi andAvakhDarestani (2015) [82]	TC		St	SO	Det	-	Ex	SF	N, -	-	3	✓	-	U	HU
Shahanaghi et al. (2015) [97]	FC, TC, PnlC	-	St	SO	Det	-	Ex	SF	N, -	-	3	✓	-	L, U	HU

Classification of the published papers in Table (2) presents the gaps of this field; hence improvements of the HFLPs and HHNPs models are demonstrated in Fig (4).

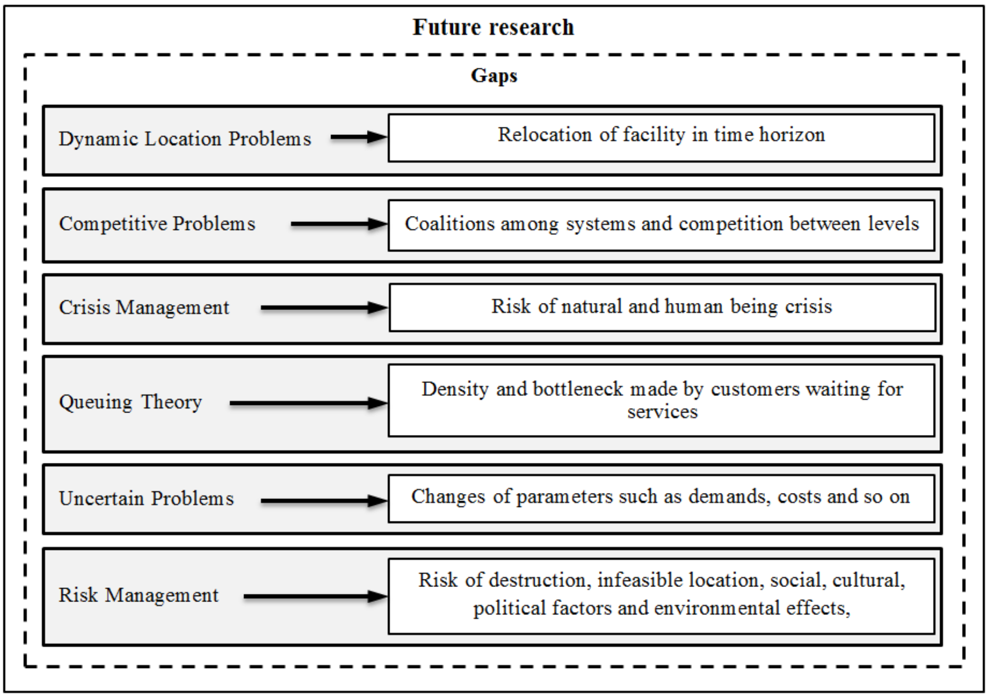

Fig.4. The scheme to developed the HFLPs and HHNPs

4- Solution approaches and algorithms for HFLPs and HHNPs

There are several solutions in every hierarchical facility location problem and hierarchical hub network which are divided by the type, structure and assumption of the problem, numbers of objective functions, constraints and dimensions. Thus algorithms can be divided in two categories such as exact algorithm, heuristic and metaheuristic algorithm, and combined solving approach which are determined by dimensions (complexity and scale) of the problem. Now if parameters of problem are considered as uncertain ones, approaches of uncertainty problems can be used too.

4-1- Application of exact solution method used for solving HFLPs and HHNPs

For the first time, in (1974), in order to solve hierarchical location problems, bender's decomposition was used for problems with small and medium dimensions which were exact algorithm. In Table (3), all the researches since 1974 until now, based on their type of exact solution approaches are explained separately.

Table 3. Exact solution method used for solving HFLPs and HHNPs

Author's (year)	Solution Technique	Commercial Optimizer Software	Description
Geofrion and Graves (1974)	Bender's Decomposition	FORTRAN	-
Charnes and Storbeck (1980)	Goal Programming	-	-
Ro and Tcha (1984)	Branch-and-Bound	FORTRAN	New application for lower bounds
Tcha and Lee (1984)	Branch-and-Bound (Dual Ascent Method)	FORTRAN	Node simplification method and implementing the dual-based sub-procedures, Dual ascent procedure and Primal Descent Procedure
Tien and El-Tell (1984)	Linear Programming Algorithm and Branch-and-Bound	MPSX	-
O'kelly and Storbeck (1985)	Exact	-	-
Flynn and Ratick (1988)	Integer Programming	MPSX	-
Kırca and Ekip (1988)	Branch-and-Bound	-	Using linear programming relaxation
Eitan et al. (1991)	Mixed Integer Programming	MPSX	-
Chung et al. (1992)	Branch-and-Bound and Dual Based Alg.	FORTRAN	-
Kim and Tcha (1992)	Branch-and-Bound	FORTRAN	Dual based lower bounding procedure
Serra et al. (1992)	Exact	MPSX	-
Gerrard and Church (1994)	Branch-and-Bound and Linear Programming Relaxation	-	Simplex method
Serra and Revelle (1994)	Branch-and-Bound	FORTRAN	Combination of linear programming and branch-and-bound
Koksalan et al. (1995)	Exact	FORTRAN, LINDO	-

Table 3. Continued

Author's (year)	Solution Technique	Commercial Optimizer Software	Description
Aardal et al. (1996)	Branch-and-Bound and Linear Programming Relaxation	-	Using cutting plan approach
Serra (1996)	Branch-and-Bound, Linear Programming Relaxation and Weighted Method	MPSX	Branch-and-Bound for non-integer solution, Weighted method for multi-objective
Aardal. (1998)	Branch-and-Bound and Linear Programming Relaxation	CPLEX	Using branch-and-bound tree for lower bound, Using strong Linear relaxations for optimal solution
Mandell (1998)	Exact	CPLEX	-
Aardal et al. (1999)	Approximation Alg. and Randomized Alg.	-	Using linear programming relaxation
Sarkis and Sundarraj (2002)	Analytical Network Process (ANP)	-	-
Espejoa et al. (2003)	Lagrangean-Surrogate (L-S) Relaxation	CPLEX	-
Sun et al. (2004)	Exact	-	Two step calculation
Horner and O'kelly (2005)	Exact	CPLEX, C++	-
Johnson et al. (2005)	Exact	CPLEX	-
Sahin et al. (2007)	Exact	CPLEX	-
Shavandi and Mahlooji (2007)	Branch-and-Bound	-	-
Thomadsen and Larsen (2007)	Branch-and-Price (IP column Generation)	-	Combination of column generation and branch-and-bound
Yasenovskiy and Hodgson (2007)	Exact	CPLEX	-
Teixeira and Antunes (2008)	Exact	Dash	-
Ratick et al. (2009)	Exact	CPLEX	-
Yaman (2009)	Exact	GAMS, CPLEX	-
Contreras et al. (2010)	Standard Cut-and-Branch Alg.	-	-
Yu et al. (2009)	Exact	LINGO	Sensitivity analysis
Ayed (2011)	Exact	CPLEX	-
Cinar and Yaman (2011)	Exact	GAMS, CPLEX	Introducing valid inequalities
Sender and Clausen (2011)	Exact	CPLEX	-
Alumur et al. (2012)	Branch-and-Bound	CPLEX	Comprehensive sensitivity analysis
Sheu and Lin (2012)	Integer Programming	LINGO	Cluster analysis
Yaman and Elloumi (2012)	Branch-and-Cut Alg.	CPLEX	CPLEX cuts
Martin de Sá et al. (2013)	Bender's Decomposition	CPLEXX, C++	Bender's decomposition method rely on Pareto-optimal optimality cuts or on rendering feasibility cuts
Rodriguez Martin et al. (2014)	Branch-and-Cut Alg.	CPLEX, C++	Solve in stances with up to 50 nodes
Rajabi and AvakhDarestani (2015)	Exact	GAMS, CPLEX	-
Shahanaghi et al. (2015)	Exact	GAMS	-

4-2- Application of heuristic and metaheuristic solution methods used for solving HFLPs and HHNPs

Heuristic algorithm for hierarchical location problem solution was first used in early (1970). As exact algorithms are not efficient for larger problems, and also with regards to existence of diversities in service levels which can increase the scale and complexity of problem, using heuristic, metaheuristic and uncertain methods (with essence of uncertain parameters) or combined algorithms seems to be helpful. All of researches about this matter, based on heuristic, metaheuristic or combined are investigated separately in Table (4).

Table 4. Heuristic and Meta-Heuristic solution methods used for solving HFLPs and HHNPs

Author's (year)	Solution Technique	Commercial Optimizer Software	Description
Schultz (1970)	Heuristic Approach	-	-
Calvo and Marks (1973)	Heuristic Approach (Branch-and-Bound, Lagrangian Relaxation)	-	Sensitivity analysis
Dokmeci (1973)	Heuristic Approach (Branch-and-Bound)	FORTRAN	Solving Non-Linear model, using a branch-and-bound method step-by-step within the same accuracy
Narula and Ogbu (1979)	Heuristic Approach	-	Greedy Heuristic, Add Heuristic, Drop Heuristic Forward Heuristic and Backward Heuristic (5 Heuristic approach)
Tien et al. (1983)	Heuristic Approach, Branch-and-Bound and Lagrangian Relaxation	-	Three zero-one integer programming formulations developed
Hodgson (1984)	Heuristic Approach	-	Modified vertex substitution heuristic
Narula (1984)	Heuristic Procedure	-	Using LR to decompose the problem and sub-gradient optimization procedure to find a lower bound for the solution
Hodgson (1986)	Heuristic Approach	-	Heuristic method allows all levels to be located simultaneously
Hodgson (1988)	Heuristic Approach	-	Sensitivity analysis
Vernekar et al. (1990)	Hybrid Simulated Annealing (HAS) and Greed Heuristic	PASCAL, LINGO	Lagrangian relaxation technique provide a lower bound for the problem
Gao and Robinson (1992)	Heuristic (Branch-and-Bound and Linear Programming Relaxation)	-	Dual Ascent Heuristic (Dual Based Optimization Procedure)
Narasimhan and Pikul (1992)	Lagrangean Relaxation (LR) and Heuristic Approach	FORTRAN	-
Narula and Ogbu (1979)	Heuristic Approach	-	Greedy Heuristic, Add Heuristic, Drop Heuristic Forward Heuristic and Backward Heuristic (5 Heuristic approach)
Tien et al. (1983)	Heuristic Approach, Branch-and-Bound and Lagrangian Relaxation	-	Three zero-one integer programming formulations developed
Hodgson (1984)	Heuristic Approach	-	Modified vertex substitution heuristic
Shaw (1993)	Greedy Alg.	-	-
Serra and Revelle (1994)	Heuristic Approach	FORTRAN	Using for large problems
Pirkul and Jayarman (1996)	Lagrangian Relaxation (LR) and Heuristic Approach	PASCAL	Using linear programming relaxation
Okabe et al. (1997)	Heuristic Approach	-	Computational and analytical Method
Tragantalerngsak et al. (1997)	Lagrangian Heuristic Approach	FORTRAN	Six heuristics based on Lagrangian relaxation
Alminyana et al. (1998)	Branch-and-Bound and Directed Branching Heuristic (DBH)	FORTRAN, CPLEX	Revised simplex algorithm with branch-and-bound-Weighted Method for multi-objective
Barros et al. (1998)	Heuristic Approach (LP-Relaxation)	-	Using linear programming relaxation
Pirkul et al. (1998)	Heuristic Approach (LP-Relaxation)	PASCAL	Using linear programming relaxation
Shmoys et al. (1998)	Approximation Alg. and Randomized Filtering Alg.	-	-
Chardaire et al. (1999)	Lagrangian Relaxation (LR) and Simulated Annealing (SA)	CPLEX	-
Marin and Pelegin (1999)	Lagrangian Relaxation and Heuristic Approach	PASCAL	Using LR, lower bounds and heuristic solutions, Several LR and decompositions of two-stage plant location models

Table 4. Continued

Author's (year)	Solution Technique	Commercial Optimizer Software	Description
Guha et al. (2000)	Approximation Alg.	-	Combinatorial approximation algorithms
Hinojosa et al. (2000)	Lagrangian Relaxation (LR) and Heuristic Approach	CPLEX, C++	-
Klose (2000)	Branch-and-Bound and Lagrangean Heuristic Relax-and-Cut Approach	CPLEX, PASCAL	A Lagrangean relax-and-cut approach for the two-stage facility location problem, Dantzig-Wolfe Decomposition Approach
Bumb (2001)	Linear Programming Relaxation, Approximation Alg. and Randomized Alg.	-	-
Marianov et al. (2001)	Heuristic Approach	-	Bi-level Heuristic (Greedy randomized adaptive search procedure (GRASP), Tabu search (TS) algorithm)
Ageev (2002)	Approximation Alg.	-	-
Galvao et al. (2002)	Lagrangian Relaxation, Heuristic Approach	CPLEX	Lagrangian based decomposition heuristic
Espejoa et al. (2003)	Lagrangean-Surrogate (L-S) Relaxation and Dual Based Heuristic	CPLEX	Dual based heuristic
Jayaraman et al. (2003)	Lagrangian Relaxation and Heuristic Approach	CPLEX, PASCAL	-
Ageev et al. (2004)	Combinational Approximation Alg.	-	Path reduction, Recursive path reduction alg., Greedy Heuristic
Lin and Chen (2004)	Implicit Enumeration Alg.	C++, C	Sensitivity analysis
Godor and Magyar (2005)	Heuristic Approach	-	Heuristic algorithm relying on iterative problem decomposition clustering methods and local optimization
Kijmanawat and Ieda (2005)	CM-GATS Alg. and Hybrid Heuristic Alg.	-	Using a stepwise solving approach called CM-GATS. Hybrid heuristic algorithm based on Genetic algorithm and Tabu search to solve each cluster
Galvao et al. (2006)	Lagrangian Heuristic Approach	CPLEX	-
Kantor and Peleg (2006)	Approximation Alg.	-	-
Ignacio et al. (2008)	Lagrangian Relaxation and, Tabu Search (TS)	FORTRAN, CPLEX	-
Lin and Chen (2008)	Implicit Enumeration Alg.	C	Sensitivity analysis
Kantor and Peleg (2009)	Constant Ratio Approximation Alg.	-	-
Miranda et al. (2009)	Heuristic Approach	-	-
Bigotte et al. (2010)	Heuristic Approach	-	-
Chen (2010)	Heuristic Approach and Tabu Search (TS)	-	Tabu search for the multiple purposes of operation planning, Implicit Enumeration Alg.
Lee and Lee (2010)	Tabu Search (TS)	C++	-
Lin (2010)	Spanning Tree Algorithm and Implicit Enumeration Alg.	-	-
Sahraeian and Korani (2010)	Heuristic Approach	GAMS, CPLEX	Heuristic method for calculating amounts of the cover radiuses
Wang et al. (2010)	Approximation Alg.	-	LP rounding algorithm
Chi et al. (2011)	Genetic Alg. (GA)	-	Humanitarian relief genetic algorithm
Costa et al. (2011)	Hybrid Decomposition Approach	-	Heuristic method to restrict tentative solutions for the vertex facilities number and computational burden of a branch-and-cut algorithm
Drexl (2011)	Approximation Alg.	-	-
Davari and Zarandi (2012)	Simulation-Embedded Variable Neighborhood Search (VNS)	CPLEX	-
Addis et al. (2013)	Branch-and-Cut Alg. and Heuristic Approach (Very Large Scale Neighborhood Search)	CPLEX, C++	Heuristic algorithms are based on two main phases: Descent Phase, (provides intensification, performing a variable neighborhood search); Kick Phase, (provides diversification in an iterated local search)
Saboury et al. (2013)	Hybrid Heuristic Approach	GAMS, CPLEX, C++	Incorporate a Variable neighborhood search (VNS) algorithm into the framework of Simulated annealing (SA) and Tabu search (TS)
Farahani et al. (2014)	Hybrid Artificial Bee Colony (HABC)	GAMS, MATLAB	The algorithm is hybridized with 2-opt as a local search
Rieck et al. (2014)	Fix-and-Optimization Scheme and Genetic Alg. (GA)	GAMS, CPLEX, C++	-
Aliakbarian et al. (2015)	Simulated Annealing (SA) and Iterated Local Search (ILS)	CPLEX, C++	Developed a branch and bound solution procedure
FazelZarandi et al. (2015)	Heuristic Alg.	-	Hybrid Alg. (Simulated Annealing (SA) with Variable depth neighborhood search (VDNS))

Published papers listed in Table (3) and (4) demonstrate less than 43% researchers have utilized Exact solution methods and more than 57% Heuristic and Meta heuristic methods to solve hierarchical hub network problems. For instance, about 31% of papers have utilized Branch-and-bound methods, about 24% Dynamic programming (DP) methods, about 9.5%Linear programming relaxation, about 7.5%Branch-and-cut, about 5% Bender's decomposition, about 2.5% Lagrangean Relaxation (LR) and about 2.5% Branch-and-price methods. In recent years, solution methods such as branch and cut, branch and price, branch and price or a combination of exact methods and heuristic or metaheuristic have been used. As most of the models in literature are assumed as they are deterministic, uncertain algorithms such as Fuzzy Approach, Robust Optimization (RO) and etc., were not used and exact solution methods are more attended.

5- Applications fields and real-life case studies

All the researches with hierarchical facility location problems and hierarchical hub network with their application fields and dataset are studied in Table (5), (6), and (7) and Figure (4). In Table (5), all the papers about hierarchical facility location problems and hierarchical hub network since 1970, based on their application, are classified, also Table (6) and Figure (4) show dataset classification, which are used in researches, and frequency percentage of every categories. Researches that have case study from real world are studied individually in Table (7).

Table 5. Applications for HFLPs and HHNPs

Applications	Author's (Year)			
Health Care Systems	Schultz (1970),	Calvo and Marks (1973),	Narula and Ogbu (1979),	Tien et al. (1983),
	Narula (1984),	Tien and El-Tell (1984),	Hodgson (1988),	Gerrard and Church (1994),
	Okabe et al. (1997),	Galvao et al. (2002),	Galvao et al. (2006),	Yasenovskiy and Hodgson (2007),
	Ratick et al. (2009),	Farahani et al. (2014)		
Emergency Medical Systems (EMS)	Charnes and Storbeck (1980),			
Education Systems	Teixeira and Antunes (2008)			
Hub Systems	Shmoys et al. (1998),	Bumb (2001),	Sarkis and Sundarraj (2002),	Kijmanawat and Ieda (2005),
	Thomadsen and Larsen (2007),	Lin and Chen (2008),	Miranda et al. (2009),	Yaman (2009),
	Yu et al. (2009),	Contreras et al. (2010),	Lin (2010),	Sahraeian and Korani (2010),
	Ayed (2011),	Chi et al. (2011),	Sender and Clausen (2011),	Alumur et al. (2012),
	Davari and Zarandi (2012),	Yaman and Elloumi (2012),	Martin de Sá et al. (2013),	Saboury et al. (2013),
	Rieck et al. (2014),	Rodriguez Martin et al. (2014)	Rajabi and AvakhDarestani (2015)	FazelZarandi et al. (2015)
	Shahanaghi et al. (2015)			
Production–Distribution Systems	Ro and Tcha (1984),	Gao and Robinson (1992),	Shaw (1993),	Koksalan et al. (1995),
	Aardal et al. (1996),	Pirkul and Jayarman (1996),	Tragantalerngsak et al. (1997),	Aardal (1998),
	Pirkul and Jayarman (1998),	Marin and Pelegin (1999),	Hinojosa et al. (2000),	Klose (2000),
	Cinar and Yaman (2011)			
Solid Waste Management Systems	Kırca and Ekip (1988),	Barros et al. (1998)		
Telecommunications Networks	Vernekar et al. (1990),	Chung et al. (1992),	Kim and Tcha (1992),	Narasimhan and Pikul (1992),
	Chardaire et al. (1999),	Lin and Chen (2004),	Sun et al. (2004),	Godor and Magyar (2005),
	Ignacio et al. (2008),	Chen (2010),	Costa et al. (2011)	
Other Systems	Dokmeci (1973),	Geofrion and Graves (1974),	Hodgson (1984),	Tcha and Lee (1984),
	Hodgson (1986),	Flynn and Ratick (1988),	Eitan et al. (1991),	Serra et al. (1992),
	Serra and Revelle (1994),	Serra (1996),	Alminyana et al. (1998),	Aardal et al. (1999),
	Guha et al. (2000),	Marianov et al. (2001),	Ageev (2002),	Espejoa et al. (2003),
	Jayaraman et al. (2003),	Ageev et al. (2004),	Horner and O'kelly (2005),	Johnson et al. (2005),
	Kantor and Peleg (2006),	Shavandi and Mahlooji (2007),	Kantor and Peleg (2009),	Bigotte et al. (2010),
	Lee and Lee (2010),	Wang et al. (2010),	Drexl (2011),	Sheu and Lin (2012),
	Addis et al. (2013)	Aliakbarian et al. (2015)		

Table 6. Classification of Data Set in the literature of HFLPs and HHNPs

Data Set Classification	Author's (Year)
Without Dataset	Schultz (1970), Eitan et al. (1991), Serra et al. (1992), Shmoys et al. (1998), Aardal et al. (1999), Bumb (2001),Ageev (2002), Sun et al. (2004), Kantor and Peleg (2006), Shavandi and Mahlooji (2007), Kantor and Peleg (2009), Wang et al. (2010), Drexl (2011)
Random Generation	Dokmeci (1973), Geofrion and Graves (1974), Narula and Ogbu (1979), Hodgson (1984), Ro and Tcha (1984), Hodgson (1986), Vernekar et al. (1990), Chung et al. (1992), Gao and Robinson (1992), Kim and Tcha (1992), Narasimhan and Pikul (1992), Serra and Revelle (1994), Aardal et al. (1996), Serra (1996), Pirkul and Jayarman (1996), Okabe et al. (1997), Tragantalerngsak et al. (1997), Alminyana et al. (1998), Pirkul et al. (1998), Chardaire et al. (1999), Marin and Pelegin (1999), Hinojosa et al. (2000), Klose (2000), Marianov et al. (2001), Galvao et al. (2002), Espejoa et al. (2003), Jayaraman et al. (2003), Ageev et al. (2004), Horner and O'kelly (2005), Kijmanawat and Ieda (2005), Godor and Magyar (2005), Galvao et al. (2006), Thomadsen and Larsen (2007), Ignacio et al. (2008), Bigotte et al. (2010), Lee and Lee (2010), Costa et al. (2011), Sender and Clausen (2011), Saboury et al. (2013), Farahani et al. (2014), Rieck et al. (2014), Shahanaghi et al. (2015), Aliakbarian et al. (2015)
From the Literature	Calvo and Marks (1973), Narula and Ogbu (1979), Charnes and Storbeck (1980), Tien et al. (1983), Tcha and Lee (1984), O'kelly and Storbeck (1985), Chung et al. (1992), Gao and Robinson (1992), Serra and Revelle (1994), Aardal. (1998), Mandell (1998), Marin and Pelegin (1999), Guha et al. (2000), Espejoa et al. (2003), Addis et al. (2013), Saboury et al. (2013), Rieck et al. (2014), Rajabi and AvakhDarestani (2015)
Real World (Case Study)	Tien and El-Tell (1984), Narula (1984), Flynn and Ratick (1988), Hodgson (1988), Kırca and Ekip (1988), Shaw (1993), Gerrard and Church (1994), Koksalan et al. (1995), Barros et al. (1998), Galvao et al. (2002), Sarkis and Sundarraj (2002), Jayaraman et al. (2003), Lin and Chen (2004), Godor and Magyar (2005), Horner and O'kelly (2005), Johnson et al. (2005), Galvao et al. (2006), Sahin et al. (2007), Yasenovskiy and Hodgson (2007), Lin and Chen (2008), Teixeira and Antunes (2008), Miranda et al. (2009), Ratick et al. (2009), Yaman (2009), Yu et al. (2009), Bigotte et al. (2010), Chen (2010), Contreras et al. (2010), Lin (2010), Sahraeian and Korani (2010), Ayed (2011), Chi et al. (2011), Sender and Clausen (2011), Cinar and Yaman (2011), Alumur et al. (2012), Sheu and Lin (2012), Yaman and Elloumi (2012), Davari and Zarandi (2012), Martin de Sá et al. (2013), Farahani et al. (2014), Rodriguez Martin et al. (2014), FazelZarandi et al. (2015)

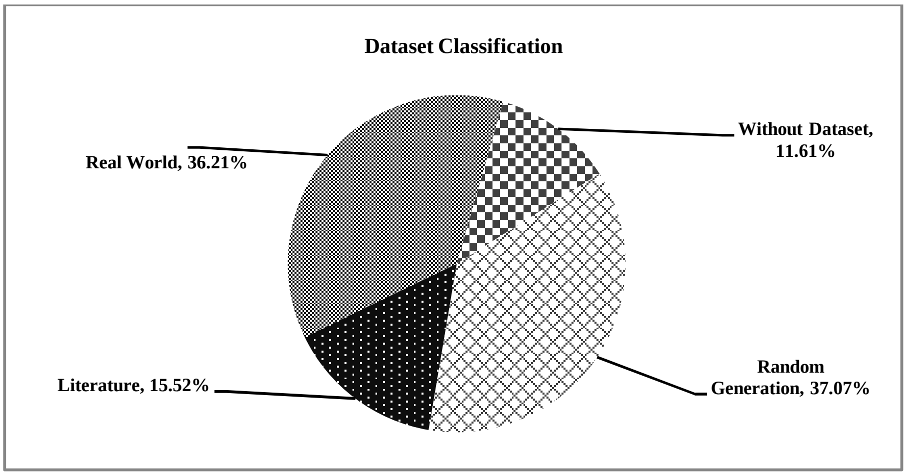

Fig.4. Frequency of dataset for each classification

Table 7. Real- Life Case for HFLPs and HHNPs

Author's (Year)	Case Study	Place (City or Region)
Narula (1984)	Problem of locating two types (Successively Inclusive) of Motor Vehicle Departments in Edmonton	Canada
Tien and El-Tell (1984)	Primary Health Care (PHC) systems coverage problem	Jordan (Mafraq District)
Flynn and Ratick (1988)	Essential Air Service (EAS)), Community air service in North and South Dakota	United States
Hodgson (1988)	Primary Health Care Delivery in a developing area	Taluka, Goa and India
Kırca and Ekip (1988)	Task of Metropolitan Municipality is conduct and manage multicounty projects, like public transportation, water works, sewage system, etc.	Turkey (Istanbul)
Shaw (1993)	Examines the structures of six Passenger airlines	United States
Gerrard and Church (1994)	Medical service planning problem in Colombia.	Colombia (Zarzal) and Uganda
Koksalan et al. (1995)	Breweries of a company	-
Barros et al. (1998)	Recycling of construction waste	Netherlands
Galvao et al. (2002)	Find the location of maternal and perinatal health care facilities in the municipality	Argentina (of Rio de Janeiro)
Sarkis and Sundarraj (2002)	Locating a repair-parts warehouse for Digital Equipment Corporation	Asia-Pacific, United States and Europe
Jayaraman et al. (2003)	Selecting hierarchical facilities in a service-operations environment	United States
Lin and Chen (2004)	Network design problem for time-definite express common carriers	Taiwan
Godor and Magyar (2005)	Universal Mobile Telecommunication System (UMTS)	-
Horner and O'kelly (2005)	Civil Aeronautics Board (CAB). Air Passenger	United States (Texas, Ohio, Pennsylvania and ...)
Johnson et al. (2005)	Location modeling methodology to a domain, elderly services	United States (Allegheny County Pennsylvania)
Galvao et al. (2006)	Load balancing and capacity constraints in a hierarchical location model in the municipality	Argentina (Rio de Janeiro)
Sahin et al. (2007)	Turkish Red Crescent Blood Services (TRC data)	Turkey
Yasenovskiy and Hodgson (2007)	Location Model for health care facilities in Suhum District, Ghana	Ghana
Lin and Chen (2008)	Federal Express Far East's Asia One Air Network, Freight Transportation	Asia Pacific
Teixeira and Antunes (2008)	Redeployment of Coimbra's Primary School Network (Public Facility Planning)	Portugal
Miranda et al. (2009)	Logistic network design problem	-
Ratick et al. (2009)	Location model for siting a hierarchical system of medical facilities	Pakistan (Kohat)
Yaman (2009)	Civil Aeronautics Board (CAB)	Turkey
Yu et al. (2009)	Urban Transit Hub Location Planning in Suchou Industrial Park in China	China (Suchou)
Bigotte et al. (2010)	Integrated modeling of urban hierarchy and transportation network	Portugal (Centro Region)
Chen (2010)	Hierarchical hub-and-spoke network of time-definite common carrier operation planning problem	Taiwan
Contreras et al. (2010)	Post Network (AP Data Set) and Civil Aeronautics Board (CAB), Hub Network Problem	Australia and United States
Lin (2010)	Hierarchical hub-and-spoke network for dual express services	Taiwan
Sahraeian and Korani (2010)	Civil Aeronautics Board (CAB), Hierarchical hub maximal covering Problem	Turkey
Ayed (2011)	Federal Express Corporation (COMP), Parcel distribution network design problem	United States
Chi et al. (2011)	Hierarchical Facility Location Model, Used Census and natural disaster data (Earthquakes)	Taiwan
Cinar and Yaman (2011)	Vendor Location Problem, Demijohn water product of The Coca Cola Company	Turkey (Ankara)
Sender and Clausen (2011)	Network design of wagonload traffic (Railway)	German
Alumur et al. (2012)	Hierarchical multimodal hub location with time-definite deliveries (Ground and Air Transportation)	Turkey
Davari and Zarandi (2012)	Civil Aeronautics Board (CAB)	Turkey
Sheu and Lin (2012)	Global logistics (GLs) network. International express delivery company (DHL)	Taiwan, China and United States
Yaman and Elloumi (2012)	Post Network (AP Data Set), star networks with service quality considerations	Australia
Martin de Sá et al. (2013)	Post Network (AP Data Set)	Australia
Farahani et al. (2014)	Consider the possibility of failure in health centers in a metropolis	Middle East
Rodriguez Martin et al. (2014)	Post Network (AP Data Set) and Civil Aeronautics Board (CAB)	Australia and Turkey
Rajabi and AvakhDarestani (2015)	Turkish data set	Turkey
FazelZarandi et al. (2015)	Civil Aeronautics Board (CAB)	Turkey

According to Table (5)the hierarchical hub network problems studied more than some other categories. From Table (6) and (7) and Figure (4) also it can be recognized that about 12 % of hierarchical facility location problems and hierarchical hub network problems without dataset and more than36% have real world case studies and about 79% of these researches were published in the last 15 years.

6. Conclusions and future trends

In this review paper, it has been attempted to prepare a trend of hierarchical facility location problems and hierarchical hub network and other relevant concepts. Also 96 published papers with this subject till 2012 based on objective functions, essence of models, parameters, constraints, techniques and solution method (exact, heuristic and metaheuristic), application and case studies (Industrial fields) are classified and investigated separately. Attending to the above classification, gapes, literature can be recognizable and our analysis on the characteristics of models, solution methods and application of published papers, suggests the following ways for future hierarchical facility location problems and hierarchical hub network modeling:

Hierarchical hub network are widely useful in hierarchal location problems, to answer customers' demands, because they have various levels of services, in these cases an expanded model should be efficient in time horizon. So, paying attention to dynamic hub location problem with configuration spatial, location and relocation of facilities is necessary.

There are varieties of systems and transportation vehicles in every network, in order to satisfy demand rapidly, systems should be capable to communicate and compete among other systems, to increase the quality of services. Therefore considering pricing and competitive market, which means designing a competitive network, can be a subject for further researches.

Till now in all the hierarchical facility location problems and hierarchical hub network location of facilities were considered as feasible. However in reality it is not possible to set facilities in some points or areas, so more attendant to physical environmental, social, cultural, political and etc. is necessary. Conditions of the place we want to choose to establish facilities, can be helpful with modeling and presenting a more feasible network.

Crisis management is more attended these years, crisis in logistic systems are divided in two general categories, first is natural crisis (for instance: earthquake, flood, storm and so on) and the second is man-made crisis (war and etc.). Considering hierarchical facility location problems and hierarchical hub network in order to overcome the natural and man-made crisis (relief logistic management) is a new trend in this matter.

One of the most important challenges in hierarchical facility location problems and hierarchical hub network is to focus on social, cultural and political criteria, environmental effects, green supply chain, green production and tent to logistic systems pollution, beside economic advantages while making a stable model. Although Jayaraman et al. (2003) has attended environmental problems, but considering mentioned factors needs more studies.

Existence of hub nodes for collection, relocation and flow distributions in a network, causes aggregation of flow and density. Therefore time waiting in a queue, as a result of aggregation, is so effective on their decision making. Optimum design of a system regardless to impression of aggregation is not possible. Using queuing theory and combining that with hierarchical facility location problems and hierarchical hub network can be helpful in real world situations, so this subject should be more considered.

Hub nodes play the main role in a hub location network, so if one of them is failed the entire network is disrupted. Considering Hub location problem is necessary to ensure a resistance against hub nodes failure. The network should keep on working in different conditions of time, one of the solutions is to consider backup hub nodes in the network and it can be studied as a research subject.

Paying attention to the changes of parameters such as demands, costs and so on in time horizon, takes us closer to probabilistic and stochastic essence of problem. Focusing on developing Probabilistic Programming (PP), Stochastic Programming (SP), Fuzzy Approach and Robust Optimization (RO) or other optimization approaches and combining them, to confront existing uncertainty, is an important approach for future researches.

Paying attention to the limitations of sources and capacities in hub location problems implements an unrealistic model. This is also assumed that sources and facilities capacity are constant and don't change therefore regarding the dynamic system problem it can be understood that available sources and facilities capacity change during the time. Hence considering the environmental conditions during the time, combining and merging them, improves the modeling in hub location problems.

Problem modeling in single objective, based on the allocation of closest facility, minimizing the costs or maximizing the covering, is more attended. Therefore considering the models with more complex objectives and several factors makes the model to tackle real world.

There are two categories of algorithms in hierarchical facility location problems and hierarchical hub network solution: (1) Exact algorithm, (2) Heuristic and metaheuristic algorithm. Using the exact algorithms was more attended in this subject, but regarding Np hard essence of this subject, in large scale problems, heuristic and metaheuristic algorithm or a combination of them needs to be used. Development of these approaches and combining them and making new approaches can provide better methods for hierarchical facility location problems and hierarchical hub network solution.

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