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Multi-Objective Single Facility Location Problem: a Review

Vaishali Wadhwa, Deepak Garg

Abstract – *Facility location problems have been the problems gaining attention of various researchers over the years. The problem is critical as it has found its application in all sectors public and private. The decision needs to be taken whenever a new facility needs to be located and where it should be located in order to maximize the profit. Here facility may be any resource that needs to be located in a predefined region e.g. any college to be located in the city, opening a new retail outlet in a metro city or locating a fire station. While locating various types of facilities, different parameters need to be considered thus resulting into several objective functions which needs to be optimized. The objective function, determined by the resource to be located and different involved constraints needs to be optimized for finding optimal location of resource. Here, in this paper we have reviewed Single Facility Location Problem and the various objective functions which include minimizing the average sum of distances, minimizing the maximum distance travelled and covering maximum demand of the customers.* ***Copyright © 2011 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords*: Facility Location Problems, Minsum, Minmax and Maximal Covering Objective*

I. Introduction

Facility location has attracted wide attention over the last four decades [1]-[24]. Facility location problem focuses on locating a resource or set of resources while minimizing the cost incurred in satisfying the demands made by different demand points. Facility location is the most critical decision element in all public and private sectors, which in turn affects various operational and logistical decisions. Decision makers must select sites that will not only perform well according to the current system state, but also will continue to be profitable for the facility's overall tenure. Thus facility location is a robust task as it involves uncertain future events. The location theory was in infancy in 1909 when Alfred Weber (popularly known the weber problem) [17] considered location of a single warehouse in order to minimize the total distance between the warehouse and several customers. After that, location theory was driven by a few applications. Location theory again gained researchers' interest in 1964 with a publication by Hakimi (1964), who wanted to locate switching centers in a communications network and police stations in a highway system.

The major components that describe location problems are: customers, who are assumed to be already located at points or on routes, facilities to be located, a space in which customers and facilities are located, and a metric that indicates distances or time between customers and facilities. Facility location problems are being used in various applications involving locating warehouses with a purpose to minimize the average time to market. Location of noxious material is handled in a manner to maximize their distance from public.

Inclusion and consideration of various factors depends upon the specific application of the problem under study. Different variants of the facility location problems like single facility location, multi-facility location, locating facility in a competitive environment, dynamic facility location problems have been addressed by various researchers.

Metrics for Facility Location Problems. The decision metric for any location problem is the distance, which gives a numeric description about how far the objects are. While locating resources, it is not only the maximum distance between the new resource and the existing resources which needs to be considered, there are various other parameters to be focused on. Most location studies focus on the minimization of the mean distance, while others try to minimize the maximum distance from any existing resource. There are various distance functions proposed by various practitioners over the time. Some of the distances are: Euclidean distance, rectilinear distance, Minkowski distance of some specified order etc.

II. Single Facility Location Problems

This is the simplest location problem where a single facility needs to be located along with the existing resources. Some examples of single facility location are locating fire station in a city, location of new class room in a building etc. While selecting a location for a single resource, various decision parameters may be involved. It is often very difficult to find a single location that meets all these objectives at the desired level. For example, a

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location in the Midwest may offer a highly skilled labor pool, but construction and land costs may be too high. This paper is mainly emphasizing on single facility location considering various objective functions defined in terms of the total travel cost and time.

II.1. Multifacility Location Problems

The above said objective also fit into multifacility location problem as well. Multifacility location problems are the problems where more than one new facilities need to be located while there are some existing facilities. The cost factors in this case are proportional to the distances between a pair of new facilities also. Ostresh (1977) [22] focused on some applications of multifacility location problems which include locating a set of warehouses to serve some existing set of servers in predefined regions, locating industrial and commercial resources where he focused on minimizing the total transport cost alone and his most fascinating work was on locating some points in large organizations where face-to-face communication should take place between the closest levels of hierarchy. Multifacility location problems are gaining more attention of the researchers than single facility location over the years. Eyster et al. [3] proposed an extension of Weizfield algorithm. For the multifacility location problem with no constraints on the location of the new facilities, Juel and Love [20] derived some sufficient conditions for the coincidence of facilities that are valid in a general symmetric metric. The results of Juel and Love [20] were later extended by Lefebvere et al. [15] to be applicable to some location problems having certain locational constraints. Mazzerella and Pesamosca [18] have used the optimality conditions of Euclidean MFLP as a tool for obtaining both stopping rules for some computational algorithms such as the projected Newton procedure of Calamai and Conn [17], and the analytical solution of many simple problems.

Various heuristics and metaheuristics were also been proposed and still are being studied by various researchers for solving such class of problems. Whatever heuristics and techniques are used, the major objectives remain same for both class of problems. Here we shall confine our survey work to the Single Facility Location Problems only.

III. Single Facility Location Problems with Multiple Objectives

Facility location is a branch of operations research that is related to locating or positioning at least a new facility among several existing facilities in order to optimize (minimize or maximize) at least one objective function (like cost, profit, revenue, travel distance, service, waiting time and coverage). The techniques developed for multi-objective location problems are trying to design the best alternative by considering various relationships between the design constraints which best satisfy the requirements of the problem solver. This is achieved by a way of attaining some acceptable levels of a set of objectives.

III.1. Location Objectives

Apart from being single objective or multi-objective, we are interested to know about various objective functions in facility location problems. Eiselt and Laporte [20] is one of the best references in classifications of objectives in location models. The objectives that are usually considered in location problems are: *minimizing the total setup cost, minimizing the longest distance from the existing facilities, maximizing service, minimizing average time/ distance traveled, minimizing maximum time/ distance traveled, minimizing the number of located facilities etc..*

Recently, environmental and social objectives based on energy cost, land use and construction cost, congestion, noise, pollution, fossil fuel disaster and tourism are also gaining popularity. Consequently, one of the most important difficulties to solve these problems is to find a way to measure these objectives and to design an accurate or at least approximate objective function for them.

III.2. Importance of Multi-objective Location Problems

The papers on handling location problems considering multiple objectives were few for many years, but in the past decade, researchers have found great interest in this class of problems. And it has opened new windows to location science in different areas. In this paper, we review some of the recent efforts and developments of multi-objective location problems.

Our survey shows that most of the work in this direction of multi-objective facility location problems started after 1990. Although there is some prior work by researchers which we have found through few sources that are not up to date. Cohon [23] in his book entitled ‘‘Multi-objective analysis of facility location problem” presented two real-world applications of multi-objective facility location problems. One of them is related to a fire station location problem in Baltimore, Maryland. In this problem Cohon emphasized on six objective functions: maximizing property value covered by new fire stations, maximizing population coverage, maximizing the area coverage, maximizing expected fires coverage, maximizing property hazard coverage and maximizing population hazard coverage. Daskin (1995) [9] considered in his work the multi-objective location problems as one of the extensions of location models. He presented two examples in location models which include locating landfills for non-hazardous materials and locating warehouses. The first one considers two objective functions: (a) maximizing location distance from population centers and (b) minimizing vehicle travel distances to waste transport. And the second is based on finding a location for a warehouse with respect to two objective functions: (a) minimizing total travel distance to demand points or customers and (b) maximizing the number of customers who receive services. Drezner and Hamacher [17] also emphasized on this concept in his book entitled ‘‘multi-objective models”. One of the most prominent classes of location problems is facility location on a network, especially in supply chain context. One example is given by Bhaskaran and Turnquist [23] in which the relation between transportation cost and coverage objectives has been studied, in a network multi-facility location. Blanquero and Carrizosa [18] proposed that how to deal with a bi-objective semi-obnoxious location problem with minsum and minmax objectives (cost and negative effect). Fernández et al. [9] presented a bi-objective supply chain design and facility location problem of supermarkets on the plane in which the main objective was to maximize the profit obtained by the chain, and the secondary objective was to minimize the difference between market shares before and after entering a new facility. These are not the only applications of facility location on a network. For example, when you are about to locate a regional rail road or subway network, you will have subtree location problems. George and ReVelle [3] have focused on Median Subtree Location Problems (MSLP) in which they minimized the cost of the subtree as well as minimized travel distance from unconnected nodes as an integer program. Current et al. [18] have considered maximum covering/shortest path problems as bi-objective integer programs with cost (minisum) and coverage (maxisum) objectives.

IV. Location Problems with *Minsum* and *Minmax* Objectives

Location problems are divided into *MinSum* and *MinMax* problems where total travelling distance is a major concern. In *Minsum* location problems the objective function is to minimize the sum of minimum distance from new resource to all existing resources thus resulting into minimum travel cost. The general formulation for Minsum objective function is as follows:

$$min\, f(x) = \sum_{i=1}^{m} w_i\, d(X_i, P_i) \tag{1}$$

where I is the indexes of the existing facilities, $d(X,P_i)$ is the distance of new facility with the existing facility i. w_i is the weight of facility i. For rectilinear distances:

$$min\, f(x) = \sum_{i=1}^{m} w_i(|x - a_i| + |y - b_i|) \tag{2}$$

The above formulation is for the rectilinear distance where straight line distances are considered, while Euclidean distance can also be considered where cost is not the linear function of the distance.

The mathematical formulation for Euclidean distance is as follows:

$$min\, f(x) = \sum_{i=1}^{m} w_i\, [(x - a_i)^2 + (y - b_i)^2]^{0.5} \tag{3}$$

Euclidian distance applies for some network locations and the locational problems involving conveyors and air travel. Some electrical wiring problems and pipeline design problems are also examples of Euclidean distance problems (Francis et al.[1]).

IV.1. Minmax Location Problems

Minmax location problem is also called the circle covering problem, which can be interpreted as the problem of covering all existing facility locations with a circle of minimum radius. MinMax problems are more specialized than MinSum problems and seem to be of interest, mainly in cases where a worst case analysis is quite important. The general formulation for Minmax location problems is as follows:

$$f(x, y) = max \left\{ \sum_{i=1}^{m} w_i\, [(x - a_i)^2 + (y - b_i)^2]^{0.5} \right\} \tag{4}$$

The circle covering problem equivalent to minimizing the $f(x, y)$ is to *minimize* a variable z, subject to:

$$\left\{ \sum_{i=1}^{m} w_i\, [(x - a_i)^2 + (y - b_i)^2]^{0.5} \right\} \leq z \tag{5}$$

The above constraints state that each existing facility location must lie in a circle with center (x, y) and radius z, so that the geometrical problem is to find a smallest circle that encloses all the existing facility locations.

Here in this paper, we are considering only the single facility location problem. The variation can be depending upon whether it is the only resource to serve demands for all demand points or it will be a mere addition to the resources in an existing network. Various techniques are existing to solve the different types of location problem, each appropriate for a specific set of objectives and constraints. For example, the Minmax location model is used for locating emergency service facilities, where emphasis is on minimizing the maximum traveled distance between facility and any possible demand points.

To find the optimal location of facilities considering various objective functions, different algorithms have been proposed by the researchers. Reza Zanjirani et al. have proposed the algorithm contour line method for point facilities which can be used if the size of facilities is considerably small as compared to the space and can be considered as points. It maintains a contour line which serves an important role if the found optimal location is infeasible due to any reason. In that case, we traverse along the contour line and thus find a feasible location for the resource. Kuhn have also proposed an iterative method for locating resources in the plane where values obtained in a particular iteration will be used in subsequent iteration to better approximate the location, thus optimizing the objective function. Minsum and minmax are the classical location problems. Theses are the major objectives and concerns for the researchers to solve any location problem. Ogryczak in 1997[15] considered not only minimizing the largest distance (center) objective, but minimizing the second largest distance, minimizing the third largest distance and so on, to bring more efficiency and equity to the solution of the problem. This author then in 1999 found another interesting development to the classic problems [25] where, instead of the traditional implementation of only center or median problems, he considered all kinds of distances as a set of multiple uniform criteria and developed a multi-objective location problem.

Drezner et al. (2006) [26] have incorporated five objectives of p-median, p-center, two maximum covering and the minimum variance in order to minimize the maximum percent deviation from the optimum of each of these objectives for a collection point location problem of a specific target .

Researchers are working on this class of problem and its variations. The recent research shows that there is still a research gap in the area of finding contour lines for Euclidean problems especially when the number of resources is larger.

V. Location Problems with Maximal Covering Objective

In many covering problems, services that customers receive by facilities depend on the distance between the customer and facilities. In a covering problem the customer can receive service by each facility if the distance between the customer and facility is equal or less than a predefined number. This critical value is called coverage distance or coverage radius. Church and ReVelle (1974) [28] modeled the maximization covering problem. Covering problems are divided into two branches: tree networks and general networks, according to their graph. In addition, these problems are divided into two problems: Total covering and partial covering problems, based on covering all or some demand points. The total covering problem is modeled by Toregas (1971). Up to the present time many developments have occurred about total covering and partial covering problems in solution technique and assumptions. Covering problem has many applications such as: designing of switching circuits, data retrieving, assembly line balancing, air line staff scheduling, locating defend networks (at war), distributing products, warehouse locating, location emergency service facility (Francis et al. 1992) [1].

Problem Formulation. The covering problem is one of well known problems of binary programming. Feasible solution space of this problem is a network (graph). In this paper we shall consider the covering problems where the capacity of facilities is considered to be unlimited. In addition, facilities are desirable; therefore, the closer to the demand point they are, more will be chances to obtain a better solution. Moreover all demand points need to be covered with minimum possible cost. The general parameters of the problem are as follow:

$i = 1,2, \ldots\ldots, m$ (Index of demand points),
M = the number of demand point,
$j = 1,2, \ldots\ldots, n$ (Index of candidate locating points),
n = the number of candidate locating point,
fj = The cost of locating a facility on candidate locating point j,
a_{ij} : is 1 if candidate locating point j can cover the demand point i , otherwise is 0.

Decision variable of model:

Xj : is 1 if a facility be located on place j , otherwise is 0.Thus the total covering problem model is as follows:

$$a_{ij}\, X_i \ \geq 1;\ \forall i \text{ and } j = 1 \ldots n \tag{6}$$

$$X_j = 0{,}1;\ \forall j \tag{7}$$

Equation (6) minimized total locating costs and (7) ensures that all demand points will be covered. Note that the eq. (7) illustrates the number of located facilities that can cover *ith* demand. In other words (7) explains that for each demand point *i*, we should locate at least one facility in one of places that can cover that demand point.

From the family of covering location problems, Badri et al. [29] have proposed a multi-objective model for a set covering problem of locating fire stations. Farhan and Murray [30] have developed a multi-objective spatial optimization model in which travel time and coverage standards are considered. Selim and Ozkarahan [32] have presented a supply chain distribution network design model that utilizes maximal covering approach in the reporting of the service level and with multiple capacity levels, through a fuzzy multi-objective model.

Covering problems have been attracting the attention of researchers from last few years. The reason is that the customer satisfaction is the major concern for problem solvers while fulfilling other objectives.

VI. Conclusion

In this paper we have reviewed the literature of SFLPs which address the multi-objective models of the problem. Our survey has explored around 25 articles which include the research work of last ten years also. Our survey has demonstrated that a large volume of work has been done in this area and that the area is still active and growing. The range and the classification of such models is very broad including planar as well network based models, probabilistic and temporal demands, private and public sector facilities, capacitated and uncapacitated versions of facilities, desirable and undesirable facilities etc.

We have addressed a few of these versions briefly and others are likely to be reviewed in near future. Moreover other directions for research could be the development of improved solution techniques because the more complex problems need specialized techniques to solve them apart from standard formulations especially for large-scale real world problems.

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Authors' information

Vaishali Wadhwa received B.Tech. and M.Tech. degrees in Computer Science & Engg. from Mahrishi Dayanand University, Rohtak and Kurukshetra University, Kurukshetra, (India) respectively. She is currently working toward the Ph.D. degree in Computer Science and engineering at Thapar University, Patiala, India, under the guidance of Dr. Deepak Garg(Astt. Prof. at Thapar University, Patiala, India). Her research interests include algorithms, soft computing, and operational research. Ms. Vaishali is currently working as Astt. Prof. in N.C.College of Engg., Israna, Panipat, Haryana (India) and proceeding her research work for the promotion of location problems and their optimization methods.

Dr Deepak Garg, Senior Member of ACM and is Chair, ACM North India SIGACT. He is Senior Member IEEE and Secretary IEEE Delhi Section Computer Society. He has more than 60 publications to his credit. His research interests are Algorithm design and complexity issues. He is having 15 years of research experience.

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