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Survey

Facility location dynamics: An overview of classifications and applications

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ABSTRACT

In order to modify the current facility or develop a new facility, the dynamics of facility location problems (FLPs) ought to be taken into account so as to efficiently deal with changing parameters such as market demand, internal and external factors, and populations. Since FLPs have a strategic or long-term essence, the inherited uncertainty of future parameters must be incorporated in relevant models, so these models can be considered applicable and ready to implement. Furthermore, due to largely capital outlaid, location or relocation of facilities is basically considered as a long-term planning. Hence, regarding the way in which relevant criteria will change over time, decision makers not only are concerned about the operability and profitability of facilities for an extended period, but also seek to robust locations fitting well with variable demands. Concerning this fact, a trade-off should be set between benefits brought by facility location changes and costs incurred by possible modifications. This review reports on literature pointing out some aspects and characteristics of the dynamics of FLPs. In fact, this paper aims not only to review most variants of these problems, but also to provide a broad overview of their mathematical formulations as well as case studies that have been studied by the literature. Finally, based on classified research works and available gaps in the literature, some possible research trends will be pointed out.

1. Introduction

A common application of FLPs includes a distributer choosing where to site a distribution center in a supply chain, a manufacturer selecting a right location for placing its warehouse, or even urban planners setting where to position a recreational facility; however, newer applications of FLPs contain location of bank accounts, database location in computer networks, vendor selection, etc. In each of these cases and also many other instances of FLPs, there will be no difficulty in dealing with system's requirements as long as factors and parameters are fixed and consistent with the planning time horizon. Such condition usually happens in static facility location problems (STFLPs). However, with the development of FLPs, STFLPs might not fulfill the requirements of a system because not only main parameters are prone to change during the corresponding time horizon, but also is a considerable amount of investment and capital required for developing or obtaining a new facility. Since facility location decisions are particularly costly and time-sensitive, they are expected to perform in the most beneficial way in a long-term period. Therefore, in order to effectively handle probable fluctuations in future as well as changing parameters, a dynamic model seems be indispensable.

From a general viewpoint, FLPs are defined in terms of two elements: space and time. By space, a planning area where facilities are located is referred, and by time, the time of location (establishing a new facility or modifying the existing facility) is indicated. According to their essence, both of space and time can be analyzed by discrete and continuous aspects. For example, if a discrete space is considered, the location of a facility can just be sited in specific points while in a continuous space, the facility is allowed to be sited anywhere in the planning area. Furthermore, discrete time means that the establishment of a new facility or the modification of the existing facility is permitted in predetermined points of time, whereas such restriction does not exist for continuous time. Such classification forms the main part of this review paper in that continuous-space, discrete-space, and network-space location problems are addressed under the category of STFLPs. On the other hand, time spans constitute the main parts of the dynamics of FLPs which forms the most important part of this paper (as a complementary research addressing other aspects of facility location dynamics, one can refer to Farahani, Abedian, & Sharahi, 2009).

Even though this paper addresses STFLPs, it puts the emphasis on dynamic facility location problems (DFLPs) and their variants. For example, one of these areas is stochastic facility location problems (SFLPs) dealing with the intrinsic uncertainty of models' parameters. In fact, such problems try to identify appropriate locations in which any configuration of random parameters in a model can be implemented. As other relevant areas, multi-period and

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single-period facility location problems (MPFLPs and SPFLPs) can be considered as discrete time span and continuous time span, respectively. In fact, in MPFLPs, a decision maker deals with changing parameters in each of several discrete-time planning horizons while in single-period models there is just one such period. Furthermore, another relevant area is the time-dependent facility location problem (TDFLP) (sometimes called demand-dependent problem), for which companies face with inconsistent demands fluctuating all over a year. Regarding these models, one of the primary instances are companies selling seasonal products. As another area, the relocation of facilities in a specific period, after they have been located, can be taken into account; meanwhile, this is called the facility location/relocation problem (FLRP). As a matter of fact, it is quite common for a firm to consider relocating its facilities over the time horizon without any potential disruption of activities in the firm.

This review paper is categorized as follows. First, STFLPs are addressed in Section 2 consisted of three parts: continuous facility location problems (CFLPs), discrete facility location problems (DIFLPs), and network facility location problems (NFLPs). Then, Section 3 throws light on DFLPs. Regarding this section, the following parts of dynamic models will be discussed: (1) dynamic deterministic facility location problems (DDFLPs), (2) FLRPs, (3) MPFLPs, (4) TDFLPs, (5) SFLPs which are relatively similar to probabilistic facility location problems (PRFLPs), and (6) fuzzy facility location problems (FFLPs). In Section 4, available literature will be discussed and classified based on their performance measures (the type of objective functions in corresponding problems). Section 5 addresses the implementation of dynamic models in terms of case studies and various applications. Moreover, Section 6 reveals some possible trends for future research, and finally, Section 7 presents the conclusion of the whole review paper.

2. Static facility location problems

As mentioned before, the space issue is as much important as the time issue in the analysis of FLPs. Due to this fact, the space issue is essentially taken into account in STFLPs while the time issue is generally discussed in DFLPs; therefore, it has been preferred to discuss static problems in this section and address dynamic problems in the subsequent section.

Now, STFLPs are thrown light on in terms of CFLPs, DIFLPs, and NFLPs. However, before going through details, it should be noted that if the space issue is considered for a FLP, two things should be identified: (1) customers with predetermined locations and (2) facilities with locations to be specified based on concerned objective function(s) (ReVelle, Eiselt, & Daskin, 2008). Therefore, the shape or topography of potential facilities will be the primary factor affecting models in continuous (plane) and discrete problems (Klose & Drexl, 2005).

2.1. Continuous facility location problems

In CFLPs, facilities are generally supposed to be located anywhere in a planning area. As a matter of fact, the performance of such models is affected by two primary factors: (1) the continuous solution space in which facilities are allowed to be sited on every point in the plane and (2) distance between facilities and customers is measured by means of corresponding distance criteria (Ballou, 1968). As applications of continuous models, the location of video cameras or pollution censors to monitor certain environments can be mentioned (ReVelle et al., 2008).

From a general point of view, CFLPs can be divided into three categories: single-facility location problems (SIFLPs), multiple-facility location problems (MUFLPs), and facility location–allocation problems (FLAPs) which will be explained as follows.

2.1.1. Single facility location problem

In the SIFLP, a new facility should be located in a way such that its distances with other facilities are minimized as much as possible; meanwhile, this distance can be defined in many terms such as Euclidean distance and Manhattan distance. As one of the primary models in SIFLPs, the generalized Weber problem can be pointed out by which the site of a new facility is selected from a set of existing facilities (Wesolowsky, 1973):

$$\text{Minimize } Z = \sum_{i \in F} w_i d(X, P_i) \tag{1}$$

According to this model, the total incurred costs are minimized, for which F is the set of existing facilities; w_i denotes a weight transforming distances into costs for the existing facility i; X and P_i respectively denote the positions of a new facility, identified by the problem, and the existing facility i; hence, $d(X, P_i)$ represents the distance between these two positions.

Even though the Weber problem is the primary type of CFLPs, for more advanced modifications of continuous problems (the location of single line and multiple lines in the plane, half-line facilities, hyperplanes and spheres, and polygonal curves), one can refer to Diaz-Banez, Mesa, and Schobel (2004).

2.1.2. Multi-facility location problem

The MUFLP is quite similar to the SIFLP; however, instead of a new facility, several new facilities must recognize their optimal locations. Concerning the interaction of SIFLPs and MUFLPs, it should be noted that each SIFLP can be transformed to its multi-facility equivalent. For example, the foregoing Weber problem can be considered with several facilities (Akyuz, Oncan, & Altnel, 2009):

$$\text{Minimize } Z = \sum_{i \in F} \sum_{j \in D} w_{ij} d(X_j, P_i) \tag{2}$$

As can be easily observed, Eq. (1) has been extended to Eq. (2), in which D is the set of new facilities; w_{ij} denotes the weight between the existing facility i and new facility j; X_j and P_i respectively denote the positions of new facility j, identified by the problem, and the existing facility i; thus, $d(X_j, P_i)$ represents the distance between these two positions. This model considers no weight between new facilities; however, another type of the MUFLP takes these weights into account (Daneshzand & Shoeleh, 2009):

$$\text{Minimize } Z = \sum_{\substack{i,k \in D \\ i<k}} v_{ik} d(X_i, X_k) + \sum_{i \in F} \sum_{j \in D} w_{ij} d(X_j, P_i) \tag{3}$$

where v_{ik} denotes the weight between new facility i and new facility k.

For more details about SIFLPs and MUFLPs as well as other variants of these problems, one can refer to Sule (2001), Klamroth (2002), Nickel and Puetro (2005), Daneshzand and Shoeleh (2009), and Moradi and Bidkhori (2009).

2.1.3. Facility location–allocation problem

The FLAP not only looks for the optimal locations of facilities, but also tries to optimally assign these facilities to customers in order to fulfill their demands. The corresponding model of this problem is as follows (ReVelle & Swain, 1970):

$$\text{Minimize } Z = \sum_{i \in D} \sum_{j \in F} C(i,j) y_{ij} \tag{4}$$

Subject to :

$$\sum_{j \in F} x_j = p \tag{5}$$

$$\sum_{j \in F} y_{ij} = 1 \quad \forall i \in D \tag{6}$$

$$x_j \geqslant y_{ij} \quad \forall i \in D,\ j \in F \tag{7}$$