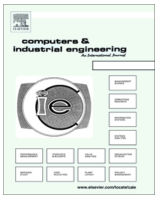
Computers & Industrial Engineering 112 (2017) 483–491

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie



Competitive facility location problem with foresight considering service distance limitations

Mingyao Qi*, Mingfei Xia, Ying Zhang, Lixin Miao

Research Center on Modern Logistics, Graduate School at Shenzhen, Tsinghua University, Shenzhen 518055, China

ARTICLE INFO

Article history:
Available online 18 April 2017

Keywords:
Competitive facility location problem
Service distance
Tabu search
Gravity-based model
Bi-level Nonlinear Integer Programming

ABSTRACT

This paper presents a bi-level, nonlinear, integer programming model for the competitive facility location problem with foresight. The developed model's objective is to maximize the leader's market share while also taking into consideration the follower's response. In the classical competitive facility location model, it is assumed that the facility competes for all customers, no matter how far away they are. Instead, this paper considers a new kind of customer behavior in which people only patronize facilities within a range they feel is convenient, which is more realistic than the existing models. To solve the model, a two-stage hybrid tabu search algorithm is proposed. A set of randomly generated instances are presented and analyzed statistically in order to illustrate the effectiveness of the proposed algorithm. The results indicate that the proposed algorithm provides an effective means to solve the problems and that service distance is proved to be a significant factor in the model.

1. Introduction

In recent years, China's express delivery industry has recorded a high annual growth. With the boom in this sector, express enterprises are willing to expand their market share. To this end, some express enterprises are determined to launch new express service stores; however, any industry competitors will react by opening new facilities in the future. This situation is one that is often encountered: one company (the leader) opens facilities in the market and another company (the follower) locates its new facilities later. This is the framework of the competitive facility location problem.

The competitive facility location problem (CFLP) differs from the classic facility location problem (FLP) in the respect that it explicitly incorporates the fact that other facilities are already (or will be) present in the market and that any new facility(ies) will have to compete with them for its (their) market share (Plastria, 2001). The competitive facility location is categorized into three categories (Ashtiani, Makui, & Ramezanian, 2013): (1) static competition, in which the competitors are already in the market and the planner of the new facilities knows their information; (2) competition with foresight, in which the potential competitors are not in the market yet but will be present soon after the new facilities are built; therefore, the leader wants to locate a facility in a qualitative way that maximizes its total captured market share after the follower located its facility; and (3) dynamic competition, in which players repeatedly re-optimize their locations. In this paper, the model under study is competition with foresight, in which two competitors successively launch their facilities with the goal of capturing the market share. Moreover, we represent decision-making solutions that consist of the following two stages. In the first stage the leader locates his new facilities to maximize his market share under the condition that he knows follower's objective function. In the second stage the follower, knowing the leader's facility information, places his facilities in order to maximize his market share (Beresnev, 2013). This sequential procedure pursues the optimal decisions for the two players, which is also known as a Stackelberg game.

The location space is also a key ingredient that affects the location model. For instance, when the location space occurs on a plane, then the new facilities can be located continuously on a two-dimensional space. However, if the location space is a discrete set and known a priori, the new facilities will be located from a set of candidate points. The customers and facilities can also be assumed to be in a network consisting of edges and vertices. For this paper's research background, we are dealing with a type of discrete set.

---

* Corresponding author.

E-mail addresses: qimy@sz.tsinghua.edu.cn (M. Qi), xiamingfei13@163.com (M. Xia), yingzhang8996@gmail.com (Y. Zhang), lxmiao@tsinghua.edu.cn (L. Miao).

http://dx.doi.org/10.1016/j.cie.2017.04.024
0360-8352/

Other fundamental categories of the competitive facility location problem are related to the customer behavior. Two customer behavior models, the deterministic model and the stochastic model, have been proposed in previous literature. In the deterministic model, it is assumed that customers patronize the facility that gives the highest utility. On the other hand, in the random model customers visit any facility with respect to some probability, typically according to the distance and the quality of the facilities.

Hakimi (1983) introduced the leader-follower issue in the competitive facility problem. He used the expression "medianoid" for the follower's problem and "centroid" for the leader's problem. In a centroid $(r|p)$ problem, the leader will locate p new facilities with the belief that the follower will invest r new facilities later. The medianoid problem $(r|X_p)$ is to locate r new facilities for the follower in order to maximize its market share, knowing that the leader has located p new facilities. Furthermore, Hakimi has proven that the leader–follower problems in $(r|X_p)$-medianoid and $(1|p)$-centroid cases are NP-hard (Hakimi, 1983). Eiselt and Laporte (1997) reviewed research work on the leader-follower problem until 1996. Plastria (2001) provided an overview of the static competitive facility location. Kress and Pesch (2012) reviewed sequential competitive location problems on networks. Shiode and Drezner (2003) presented the competitive facility location problem on a tree network with stochastic weights. Ahn, Cheng, Cheong, Golin, and Van Oostrum (2004) considered that two players each successively place one facility into the market, until each of them has placed n facilities. Beresnev (2013) proposed a branch-and-bound algorithm for the competitive facility location problem. Ashtiani et al. (2013) provided a robust model for determining optimal locations for the leader's new facilities when the number of the follower's new facilities is unknown. Plastria and Vanhaverbeke (2008) solved the competitive location problem with foresight in which the competitor will locate a single new facility. Alekseeva, Kochetova, Kochetov, and Plyasunov (2010) worked with regard to the discrete $(r|p)$-centroid problem, based on deterministic customer behaviors. Shiode, Yeh, and Hsia (2012) investigated the optimal location policy for three competitive facilities. Unlimited to the facility location decision, some recent studies have examined the facility design aspects simultaneously; for instance, matters relating to size, product variety, and so on. This kind of problem is known as the competitive facility location-design problem; see detailed reviews in Aboolian, Berman, and Krass (2007), Redondo, Fernández, García, and Ortigosa (2010), Küçükaydin, Aras, and Kuban Altınel (2011), Sáiz, Hendrix, and Pelegrín (2011), Fernández, Salhi, and Tóth (2014), Saidani, Chu, and Chen (2012), Wang and Ouyang (2013). Table 1 lists some of the relative studies, classifying them in terms of game theoretic aspect, location space, customer behavior and location and design.

Based on the related literature, the conclusion can be drawn that few researchers have considered service distance limitations when modeling the competitive facility location problem. All previous papers have assumed that the customer can be serviced by any facility in the market; however, this assumption is not always realistic. For example, in the express service store-location problem, the facility's service distance is taken into consideration: the store will only capture the customers within the service distance.

For this paper we have taken into consideration the facility's service distance in the competitive facility location problem with foresight. The remainder of the paper is organized as follows. Section 2 presents the notations and our model. The algorithm is explained in Section 3. Numerical examples and computational results are given in Section 4. Section 5 concludes the paper and presents directions for future research.

2. Model description

A two-dimensional market region is considered in which the demand is assumed inelastic and is supposed to be concentrated in n demand points. Two competitors, both providing identical services, are referred to as the leader and the follower. There are m facilities; of these facilities, the leader owns t facilities and the follower owns the rest of the m-t facilities. The existing facilities are placed in m of n demand points and the remaining n-m points can be regarded as potential locations. The leader intends to locate p new facilities in the potential locations, given that the follower will surely respond to his action by launching r new facilities in the potential locations. It is assumed that only one new facility can be opened at each potential location.

The customer's behavior is important in the competitive facility location problem, because it is necessary to describe the demand captured by each competing facility in a precise manner. With regards to the facility's service distance limitations, this paper incorporates a new kind of customer behavior that states people will only patronize facilities within a range they feel is convenient. First, when the customer is within a facility's service distance, the customer behavior follows a random model; in other words, his demand is split by these facilities. Second, if the customer is within only one facility's service distance, the customer's behavior follows a deterministic model such that his full demand is serviced by this facility. Finally, if the customer is beyond any facility's service distance, his demand is unserved. The quality levels of all facilities are assumed to be predetermined.

Table 1
Selected researches and classification.

Authors and year	Game theoretic aspect	Location space	Customer behavior	Location and design
Ashtiani et al. (2013)	With foresight	Discrete set	Probabilistic	Location
Beresnev (2013)	With foresight	Discrete set	Deterministic	Location
Hakimi (1983)	Static	Network	Deterministic	Location
Shiode and Drezner (2003)	With foresight	Network	Deterministic	Location
Ahn et al. (2004)	Dynamic	Plane	Deterministic	Location
Plastria and Vanhaverbeke (2008)	With foresight	Discrete set	Deterministic	Location
Alekseeva et al. (2010)	With foresight	Discrete set	Deterministic	Location
Shiode et al. (2012)	With foresight	Network	Deterministic	Location
Aboolian et al. (2007)	Static	Discrete set	Probabilistic	Location and design
Redondo et al. (2010)	With foresight	Plane	Probabilistic	Location and design
Küçükaydin et al. (2011)	With foresight	Discrete set	Probabilistic	Location and design
Sáiz et al. (2011)	With foresight	Discrete set	Probabilistic	Location and design
Fernández et al. (2014)	With foresight	Plane	Deterministic	Location and design
Saidani et al. (2012)	With foresight	Plane	Probabilistic	Location and design
Wang and Ouyang (2013)	With foresight	Discrete set	Deterministic	Location and design