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A location-inventory-pricing model in a supply chain distribution network with price-sensitive demands and inventory-capacity constraints

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ABSTRACT

This paper presents a location-inventory-pricing model for designing the distribution network of a supply chain with price-sensitive demands and inventory-capacity constraints. The supply chain has market power and uses markup pricing. An efficient Lagrangian relaxation algorithm is proposed to solve the model. Our numerical study shows that by moderately increasing the number of possible values for pricing decisions, the model can be used to find near-optimal solutions of a similar location-inventory-pricing problem with continuous pricing decisions. The approach used here to incorporate pricing decisions can be applied to other supply-chain design and planning problems with price-sensitive demands.

1. Introduction

Traditionally, the storage and the distribution of goods have been managed separately. However, today, it is a known fact that incorporating inventory decisions into location models, as originated by Baumol and Wolfe (1958), is more profitable for the whole system. *Location-inventory problems* (LIPs) are basically integrated discrete location problems that determine location, allocation and inventory decisions simultaneously. LIPs can be applied to most businesses where inventory management plays an important role in the production and distribution systems.

LIPs have received much attention in the literature in the past decade. Several papers deal with LIPs with cost-minimization objectives in a two-echelon supply chain under different assumptions: see, e.g., Erlebacher and Meller (2000), Daskin et al. (2002), Shen et al. (2003), Miranda and Garrido (2004, 2006, 2008), Shu et al. (2005), Shen (2005), Snyder et al. (2007), Ozsen et al. (2008), and Atamtürk et al. (2012).

LIPs with cost-minimization objectives have been extended in several directions. For example, routing decisions are incorporated in LIPs in Ahmadi-Javid and Azad (2010) and Ahmadi-Javid and Seddighi (2012). Joint replenishment inventory-location models are proposed in, e.g., Silva and Gao (2013) and Qu et al. (2015). The effect of disruption on the decisions made in LIPs are studied in, e.g., Qi et al. (2010) and Chen et al. (2011a). Multi-echelon location-inventory models are investigated by, e.g., Diabat et al. (2013) and Shahabi et al. (2013). Some works consider multi-source distribution

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networks, e.g., Yao et al. (2010) and Ahmadi-Javid and Seddighi (2012); and others develop multi-objective models for LIPs, e.g., Liao et al. (2011a,b).

Most of the works on LIPs have cost-minimization objectives, but a few papers have studied *profit-maximization LIP* (PM-LIP) models. Shen (2006) and Shu et al. (2012), for example, considered PM-LIPs with demand choice flexibility, which was originally introduced in the discrete location literature, for example, by Zhang (2001) and Meyerson (2001). In PM-LIPs with demand choice flexibility, the prices only affect customers' decisions on whether or not to get service, and the demand volumes are independent of the pricing decisions.

Despite the fact that location problems with price-sensitive demands have been studied in the literature of facility location–allocation problems by several papers, e.g., Wagner and Falkson (1975), Hansen et al. (1981), Hanjoul et al. (1990), Hansen et al. (1997), and Ahmadi-Javid and Ghandali (2014), the paper by Ahmadi-Javid and Hoseinpour (2015) is the only one that considers a PM-LIP with price-sensitive demands where each open distribution center (DC) has an unlimited storage capacity and offers a unique price to all of its customers.

The current paper considers a more realistic PM-LIP with price-sensitive demands. The proposed PM-LIP is formulated as a *mixed-integer nonlinear program* (MINLP) and successfully solved by the Lagrangian relaxation (LR) method, which is proven to be very powerful in solving MINLPs developed for LIPs.

Compared to Ahmadi-Javid and Hoseinpour (2015), this problem has two new features: (i) each DC has a limited storage capacity and (ii) each DC can offer different prices to its customers. From a practical viewpoint, these new features are highly important. Indeed, in practice, each DC has limited storage space, which significantly affects customer allocation to open DCs. Moreover, when a supply chain can offer customers (demand points or spatial markets) different prices, it is more profitable for it to consider a full price differentiation rather than a partial one which dictates that all prices offered by each open DC are identical. From a computational perspective, considering inventory constraints naturally makes LIPs quite difficult, such that, in the literature, there are only a few papers that consider storage-capacity constraints, for example, Miranda and Garrido (2006, 2008), Ozsen et al. (2008) and Atamtürk et al. (2012). The reason behind this difficulty may be that, when the inventory capacity of DCs is limited, the decision variables corresponding to order-size quantities at DCs become bounded, and one cannot achieve a pure integer-programming model with known properties by removing order-size decisions from the formulation. Moreover, considering full price differentiation enormously increases the feasible solution space, compared to the partial price-differentiation case, where each open DC offers a unique price to all of its customers.

Our work is also related to integrated models in which price and inventory decisions are made simultaneously. There is a considerable literature dealing with these models: see, for example, Chen et al. (2006, 2011b), Chen and Simchi-Levi (2012), Chen and Hu (2012), Güler et al. (2014), and the recent book chapter by Simchi-Levi et al. (2014).

A systematic analysis of business areas that use markup pricing has been developed in industrial organization theory, which is a branch of economics. In this theory, the ability of a firm to affect the price in the market of a good or service is called its *market power*. A firm with market power uses *markup pricing* to determine a markup over its marginal cost (Wolfstetter, 1999; Pindyck and Rubinfeld, 2005). In the two extreme cases of a monopoly and a perfectly competitive market, a firm has the maximum and minimum possible market power, respectively. Significant sources of market power are entry barriers preventing competition in the market (McAfee et al., 2004). The main barriers are government-created ones (e.g., pharmaceutical companies with governmentally granted patents), control of scarce resources (e.g., international organizations controlling oil and gas), technological superiority (e.g., companies with high design and production abilities) and increasing returns to scale (e.g., superior IT companies or global automobile manufacturers). The reader may refer to, e.g., Tirole (1988) and Belleflamme and Peitz (2010) for more theoretical details.

Markup pricing is used in more than 75% of industries, according to some case studies (Ray et al., 2005), and in many sectors (Baba, 1997), such as in organic production (Lohr and Park, 1999), petroleum refining (Considine, 2001), and retailing (Pradhan, 2006). Therefore, the model presented in this paper can be applied to designing the distribution networks of similar industries.

The rest of the paper is planned as follows. Section 2 states and formulates the considered problem. Section 3 presents the LR algorithm, and Section 4 reports the computational experiments. Section 5 concludes the paper.

2. Problem statement and formulation

The PM-LIP under consideration is first described in Section 2.1, and is then formulated in Section 2.2.

2.1. Problem statement

The proposed PM-LIP simultaneously determines the location of distribution centers (DCs), the allocation of customers (demand points or spatial markets) to open DCs, the order quantities at open DCs, and the retail prices offered by each DC to its allocated customers in a supply chain distribution network with inventory-capacitated DCs and price-sensitive