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Modeling logistics service providers in a non-cooperative supply chain

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ABSTRACT

This paper presents a mathematical model for the design of a non-cooperative supply chain where transportation activities are provided by logistics companies. We consider a four-layer network comprised of manufacturers, retailers, customers, and logistics service providers (LSPs). In this problem, manufacturers, retailers, and LSPs do not collaborate or engage in any type of bargaining strategy among one other. Instead, they compete to supply products to customers at demand markets, while each agent seeks to maximize his own profit. LSPs compete among themselves to provide logistics (transportation/warehousing) services to manufacturers. It is considered that manufacturers, LSPs, and retailers collaborate to maximize services. Normally this problem cannot be modeled as an optimization problem, so we use a variational inequality approach to formulate it. To the best of our knowledge, this important problem, which helps evaluate options and make decisions when logistics activities are provided by LSPs, has not been modeled in the literature and this constitutes our main contribution. The model determines the optimal level of production for each manufacturer, the flow of products between manufacturers and retailers, the flow of products to be handled by each logistics service provider and the flow of products between retailers and demand markets in a non-cooperative environment. Numerous experiments are presented and adapted from test examples that are available in the literature, while results and important findings are discussed.

1. Introduction

In today's business setting, where firms face fierce competition and reduced margins, increasing profits can be achieved through effective planning, design and management of the entire supply chain [42]. The motivation for improved Supply Chain Management (SCM) is associated with new challenges and opportunities, such as the integration and coordination of inter-organizational efforts. The vast amount of published work, especially in the last twenty years, reflects the great interest of the academic and business world towards SCM, which has been applied to a wide variety of disciplines, including finance, logistics, operations management, operations research and information technology, among others [20,24,31].

In an attempt to maintain globally competitive performance standards, many firms have outsourced some of the activities that are not part of their core competences. To speed up the introduction of products and services, firms have outsourced their logistics activities to logistics services providers [29]. As a result, the logistics service industry has experienced continuous growth

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since the late 1980s, when it was recognized as a new industry sector [56]. According to a recent study, the global 3PL market revenues for 2010 were estimated in the US at $541.6B [30]. As firms continue to outsource manufacturing and sales among different countries and regions, their transportation, distribution, and inventorying activities will continue to be complicated, and the demand for contracting LSPs will continue to grow [34]. In the published literature, LSP is also referred to as third-party logistics (TPL or 3PL), and it can be defined in many different ways (see, for example, [25]). For the purpose of this paper, an LSP is defined as a provider of logistics services that performs all or part of a client company's logistics functions [10,11].

The definition of a supply chain that we adopt is that it is a chain of relationships which synthesizes and integrates the movement of goods between manufacturers, logistics service providers, retailers and consumers (see [26]). We focus on a multiple layer supply chain with decision makers, be they manufacturers, LSPs, retailers and consumers, who compete within a single layer and make transactions between the different layers; the governing concept, assuming individual optimizing behavior, is that of a network equilibrium (see for example, [47]). A certain level of coordination between layers of the supply chain is necessary so that the product flows can move downstream via transactions from the manufacturers to the consumers who are located at distinct demand markets. Nevertheless, our problem does not address any type of cooperation in the supply chain, nor have any coordination mechanisms such as quantity discounts, credit options or return policies, been considered. A discussion on cooperation in supply chains can be found in Nagarajan and Sošić [43], while coordination mechanisms are discussed in Sarmah et al. [54], Li et al. [33] and Rahdar and Nookabadi [52]. Finally, problems involving cooperation have been studied by Lin and Hsieh [35] and Asgari et al. [4], to name a few.

In this paper we propose a mathematical model for the design of a non-cooperative supply chain network where logistics activities are outsourced to logistics service providers. To some extent, the characteristics of our problem resemble some elements that exist in the general equilibrium theory of markets [3,39] where producers are seeking to maximize their profit, consumers pretend to maximize their utility and a set of prices exist that clear the market (equilibrium of the economy) and make possible the optimization of each individual. However, the current model extends previous supply chain network models in several ways. Firstly, we consider explicitly that LSPs interact with other organizations in the supply chain and that they compete for the opportunity to provide logistics services to manufacturers. Secondly, LSPs take products from manufacturers and deliver those same products to retailers without charging them. Thirdly, the service price and quantity of products to be transported from manufacturers to retailers are determined in a way that ensures maximum profit for the LSPs. To the best of our knowledge, this is a novel model that considers LSPs' activities in a non-cooperative supply chain network.

This paper is organized as follows. In Section 2 we provide a review of relevant literature. In Section 3 we formulate the supply chain design problem involving the operation of logistics services providers, whose work is derived from the manufacturers' demand to deliver products to their customers. In Section 4 we present a model of the integrated supply chain problem. Finally, in Sections 5 and 6, we present some numerical examples and our conclusions, respectively.

2. Literature review

For a detailed review of Supply Chain Network Design problems and modeling approaches, the reader is referred to Melo et al. [40], who conduct a detailed literature review of facility location models in the context of Supply Chain Management and focus primarily on applications specific to Supply Chain Network design. The works reviewed follow the traditional Supply Chain Network design models where there is no competition among the agents (companies, organizations) and the models and solution methods are focused on facility location. For example Bachlaus et al. [5] propose a multi-objective mixed integer optimization model to design a multi-echelon supply chain network. However, in the general case, the type of problem we address in this paper cannot be modeled as an optimization problem; hence, we use a variational inequality approach to formulate the problem. Normally, the complexity of this problem derives from considering cost functions for the supply chain members who are dependent on one another, so the Jacobian matrix of the cost functions is no longer symmetric. For concepts and applications related to network design in a broader context, the reader is referred to Ahuja et al. [1]. For additional background on supply chains, see Pardalos and Tsitsiringos [51], and the more recent volume by Simchi-Levi et al. [57].

The impact of competition in the design and management of supply chains has been studied by Nagurney et al. [47], and their supply chain network models focus on competition among decision-makers such as manufacturers, distributors, and retailers at a tier of the supply chain but they presumed cooperation among those tiers. Zhang et al. [62] and Zhang [61], on the other hand, model competition among supply chains in a supply chain economy context, without considering explicit firms. Dong et al. [17] develop a supply chain network model where a finite-dimensional variational inequality is formulated for the behavior of various decision-makers. Nagurney et al. [46], in contrast, propose a modeling framework to analyze the dynamics of global supply chains. The authors assume competitive firms and model three tiers of decision-makers: manufacturers, retailers, and consumers; they derive a variational inequality formulation to investigate the global supply chain network along with its qualitative properties.

As far as the integration of supply chain decisions is concerned, it has been addressed by several authors; Diabat et al. [14] study the capacitated facility location problem with risk pooling, which is an integrated location and inventory problem. The authors assume that retailers can serve as distribution centers (DCs), in order to achieve risk pooling. Le et al. [32] integrate inventory and routing for perishable goods, while Diabat et al. [15] study the multi-echelon joint inventory-location (MJIL) problem that simultaneously decides the location, order assignment and inventory levels. Diabat [12] addresses the problem of vendor managed inventory (VMI), while perishable goods are also considered in the work of Diabat et al. [13]. Finally, Diabat and Richard [16], develop a nested Lagrangian relaxation approach to solve the joint facility location inventory model.