Computers & Industrial Engineering 72 (2014) 129–142

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

Supply chain network design under oligopolistic price and service level competition with foresight ☆

Shabnam Rezapour [a], Reza Zanjirani Farahani [b,*]

[a] The School of Industrial and System Engineering, The University of Oklahoma, Norman, OK, USA
[b] Department of Management, Kingston Business School, Kingston University, Kingston Hill, Kingston Upon Thames, Surrey KT2 7LB, UK

ARTICLE INFO

Article history:
Received 6 January 2012
Received in revised form 5 January 2014
Accepted 3 March 2014
Available online 24 March 2014

Keywords:
Supply chain management
Network design
Nash equilibrium
Fractional programming

ABSTRACT

In this paper a new bi-level model for designing the network structure of a competitive supply chain (SC) is presented with anticipating variable prices and service levels competition in markets under stochastic price and service level dependent elastic demands with the presence of existing, external rivals. The network structure of the new entrant SC would be designed under the limited production capacity of its producers in a way to maximize its future capturable profit in the competitive markets. The network of the new SC is assumed to be set "once and for all" but further price and service level adjustments are possible. Outer part of this bi-level model deals with strategic decisions of SC network design. Given the SC network structure assigned by the outer model in each iteration, the inner equilibrium model determines the equilibrium retail prices and service levels. Finally, we illustrate the model through several numerical examples.

1. Introduction

The nature of competitions is gradually changing in today's business environment. Traditional company against company competition is giving way to supply chain (SC) against SC competition. According to the Deloitte Consulting's (1999) report "no longer will companies compete against other companies, but total SCs will compete against other SCs". Taylor (2003) mentions that "in 21st century, being the best at producing and or selling a superior product is no longer enough. Success now depends on assembling a team of companies that can rise above the win/loss negotiations of conventional trading relationships and work together to deliver the best products at the best price. Excellence in manufacturing is just the admission fee to be a player in the larger game of SC competition".

Several examples of this kind of competition recently have occurred in business. There are many real-life examples of competing SCs in airline industry, maritime shipping, automotive industry, retailer industry, pharmaceutical SC, online bookstores and apparel manufacturing (Farahani, Rezapour, Drezner, & Fallah, 2014). Gradually, more companies have become aware of the importance of an effective competitive SC for success and survival. But unfortunately there are few academic research works that consider the competition among SCs investigating the effects of this competition on the various decisions made in the SCs. Great deal of works have been done in the literature of SC assume monopoly market for the chain. To accompany with the needs of practical world and to fill this important gap of the literature, in this paper we consider the problem of designing the network structure of a SC that works in competitive markets in the presence of several rivals; we will investigate how the effects of this future competition can be considered in designing its network structure.

In severely competitive markets, SCs need to manage inventories and material flows costs in SC network structure efficiently. Consequently SC network design (SCND) is significantly considered as primary and main source of reducing costs in SCs (Simchi-Levi & Kaminsky, 2004). SC planning considers the management of material flows along the network but also considers location and capacity decisions of facilities in various echelons of SCs. Most of the previous works on SCND assume the monopoly of servicing the markets (Shen, 2007). One of the most important factors which should be considered in designing a new chain is the existence of rivals providing the same or substitutable products. When no other rivals exist, the new chain will play its role in a monopoly market. But in presence of rivals, the new chain will have to compete for its market share. Ignoring the impact of possible external competition

☆ This manuscript was processed by Area Editor Iris F.A. Vis.

* Corresponding author. Tel.: +44 (0)20 8417 5098; fax: +44 (0)20 8417 7026.
E-mail addresses: Zanjiranireza@gmail.com, R.ZanjiraniFarahani@kingston.ac.uk (R. Zanjirani Farahani).

http://dx.doi.org/10.1016/j.cie.2014.03.005
0360-8352/

is unrealistic and can lead to a significant bias in the SC's income prediction and its network structure selection.

The idea and model presented in this paper contain elements of competition and SCND and combine them in a unique manner to improve the efficiency of SCND decisions; this is done by predicting the competition ability provided by these SCND decisions for the new chain compared to its rivals in the markets.

There are three types of competition in the literature as follows:

(a) Static competition: This is applicable where the new entrant SC rival intends to make decisions facility while it knows other rivals exist and is informed from their strategic competition factors (such as location and quality of retail outlets) which cannot be changed in the near future. Due to the static nature on this competition, mathematical models are usually developed to model this competition (Aboolian, Berman, & Krass, 2007; Benati & Hansen, 2002; Drezner, Drezner, & Salhi, 2002; Fernandez, Pelegrin, Perez, & Peeters, 2007; McGarvey & Cavalier, 2005; Zhang & Rushton, 2008).

(b) Competition with foresight: In this case there is not any rival in the market now but they may emerge soon afterwards. Therefore, prediction of these future competitions and their effects is necessary in the decision making process which leads to Stackelberg game (Chawla, Rajan, Ravi, & Sinha, 2006; Plastria & Vanhaverbeke, 2008; Shiode & Drezner, 2003).

(c) Dynamic competition: In this situation the rivals simultaneously make decision about operational competition factors such as retail prices, service levels and production qualities. Nash equilibrium is usually used to model this kind of competition (Ahn, Cheng, Cheong, Golin, & Oostrum, 2004; Anderson & Bao, 2010; Bernstein & Federgruen, 2003, 2004, 2005, 2007; Boyaci & Gallego, 2005; Carr & Karmarkar, 2005; Corbett & Karmarkar, 2001; Tsay & Agrawal, 2000).

In the past price was considered as the most important competition factor, but recently IT is making rival firms charge almost similar prices for comparable product. Thus market share gains go to the rivals offering higher service levels. In most of today's markets retail price and service level are considered as the most important competitive factors which extensively affect the competition ability and consequently the profitability of the rival SCs. Recently many vendors specify time windows for order delivery times (Bernstein & Federgruen, 2004).

However the nature of setting retail prices and service levels and SCND decisions are completely different. Pricing and setting service level are kind of operational decisions which can be adjusted in short run but SCND include strategic decisions which remain fixed for a long time. In this paper we show that how these two naturally-different but highly-interactive decisions can be considered in the SCND problem together. The results obtained in this paper show that considering the preferences of the markets' customers is critical in the network design problems of SCs working in competitive markets. Because customers' sensitivities respect to the competitive factors affects the network's market share, its profitability and consequently can significantly change the structure of its selected network. Our objective is to develop a model for designing a new entrant SC's network by anticipating its dynamic price and service level competitions with existing rivals in the future. In this model each rival choose a service level and pricing strategy with an appropriate inventory level.

Demand formulation and assignment is very important in competitive environment. Various kinds of demand functions have been considered in the literature of competition. Sometimes demands of rivals have been considered as functions of service levels (Boyaci & Gallego, 2005; Ernst & Cohen, 1992; Ernst & Powell, 1995, 1998). In some research papers, demands of rivals depend on prices (Anderson & Bao, 2010; Bernstein & Federgruen, 2005; Jiang & Wang, 2009; Majumder & Srinivasan, 2008; Meng, Huang, & Cheu, 2007). Several economists have mentioned that considering demand as a function of only sale prices cannot explain the customers' behavior in a good way. Hence, gradually researchers considered other additional attributes variables; for example, "price and service level" (Bernstein & Federgruen, 2004, 2007; Tsay & Agrawal, 2000; Xiao & Yang, 2008), "price and distance" (Fernandez et al., 2007), "distance" (Berman, Drezner, & Wesolowsky, 2003; Plastria & Vanhaverbeke, 2008; Shiode & Drezner, 2003), "distance and one or more attractiveness attributes" (Aboolian et al., 2007; Drezner et al., 2002; Zhang & Rushton, 2008) were investigated. For anticipating the future competition of rivals we use a stochastic equilibrium model in which rivals compete in terms of their sale prices and service levels. To build this equilibrium model, we propose a stochastic linear demand model. Linear demand functions are tractable and often gives an acceptable fit to the given data set (Kurata, Yao, & Liu, 2007).

In this paper we assume that the new chain's network structure remains fixed once chosen, but price and service level adjustments are still possible (Eiselt & Laporte, 1996). In literature usually hieratical decision making process is used for these kinds of problems which is easily implementable but leads to a sub-optimal solution for the problem. To avoid sub-optimality, instead of hieratical decision making, we formulate this problem with a new version of bi-level programming. This approach would be more complicated but ensures the global optimal solution for the problem. Like Bernstein and Federgruen (2004) we assume there is a linear elasticity between competitive factors and markets' demands; stochastic part of the demand has a multiplicative form. Unlike this paper, Bernstein and Federgruen (2004) only consider competition in the retailer level and neglect their upstream facilities in the form of a SC. In the other word, work of Bernstein and Federgruen (2004) has nothing to do with the SC concept and investigating the effects of the SC's network structure on the competition ability of its retailers is not part of that work.

This paper develops a model for competitive SCND in markets with linear price and service level dependent demands. The contributions of this paper to the SCND literature are as follows:

- Instead of unrealistic monopoly markets assumption which is prevalent in the literature, our SCND model considers competitive markets with existing external rivals. We assume that rivals supply products to the market which are either the same or substitutable.
- Our problem includes two different kinds of decisions: strategic and operational decisions. Instead of hieratical decision making process which is mainly used in the literature, we formulate this problem with a new version of bi-level programming to make these two decision simultaneously which is much more efficient than the hierarchical way.
- We solve the bi-level model and test it using numerical examples. The results show that considering the preferences of the markets' customers is critical in SCND in competitive markets because customers' sensitivities respect to competitive factors affects the chain's market share, its profitability and consequently can significantly change the structure of its selected network.

The paper is organized as follows. Problem description and general explanation of its modeling approach are included in Section 2. Section 3 illustrates the framework of the modeling and solution approach in this paper. Rivals' competition in the markets is formulated in Section 4 (inner part of the bi-level model). In Section 5, we present the mathematical SCND model (outer part of the bi-level model). A solution approach is presented in Section 6 to solve the presented mathematical model. Section 7 presents the solutions' sensitivity to demand functions' parameters. Section 7 concludes and gives directions for further research.