International Journal of Production Economics 196 (2018) 150–162

Contents lists available at ScienceDirect

International Journal of Production Economics

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

Optimizing the supply chain configuration and production-sales policies for new products over multiple planning horizons

Ashkan Negahban [a,*], Mohammad Dehghanimohammadabadi [b]

[a] School of Graduate Professional Studies, The Pennsylvania State University, Malvern, PA 19355, USA
[b] Department of Mechanical and Industrial Engineering, Northeastern University, Boston, MA 02115, USA

ARTICLE INFO

Keywords:
Mixed-integer nonlinear programming
Innovation diffusion
Production and sales plans
Multi-echelon inventory system
Supplier selection
Supplier switching cost

ABSTRACT

The objective of this paper is to jointly optimize supplier selection, pipeline and safety stock inventories, and production-sales policies for new products over multiple planning horizons such that the total profit over the product's life-cycle is maximized. A mixed-integer nonlinear programming model is proposed that not only allows for adjusting the level of pipeline and safety stocks at different supply chain stages, but also for switching suppliers and/or modifying their demand allocations in different planning horizons in response to changes in the new product's demand. A representative supply chain network for computer assembly is then used to illustrate the applicability of the model. The findings from our numerical experiments with the model can potentially have important implications for future research and practice. In contrast to the traditional understanding of flexibility, the results indicate that the total profit may not necessarily be an increasing function of the number of planning horizons. The performance of commonly used heuristic policies for supplier selection as well as different myopic and build-up production-sales policies are also compared with the model's prescribed solutions in order to provide insight on when such heuristic policies and combinations thereof can be effective. The interdependency between supplier switching cost and the number of build-up periods is also illustrated.

1. Introduction

Once the research and development (R&D) phase for a new product is complete and the production processes are determined, firms need to identify and select the options to supply each production stage (e.g., vendors, manufacturing technologies, and shipment options). Consider a multi-echelon supply chain network for a new generation of personal computers (PC) in Fig. 1 adapted from case studies in Kilger et al. (2015) and Li and Amini (2012). Component C1 can be sourced from three suppliers located in East Asia, South America, and a local supplier in the United States. Similarly, there are three shipment options for the finished product (stage F) to its European market, namely container shipment by ocean and regular and expedited air shipment. If multiple options are selected, then the demand for that stage needs to be properly distributed among the suppliers. Options (suppliers) often differ in terms of direct cost (e.g., material, processing, labor, handling and transportation costs) and lead time (i.e., from the time a stage reorders to the completion of the function at the stage), which in turn affects pipeline and safety stocks. Also, there is often an inverse relationship between the lead time and direct cost of the potential options. Moreover, supplier selection at any stage will affect the cost and responsiveness of other production stages. As a result, firms generally face the dilemma of compromising between manufacturing cost and supply chain responsiveness.

When introducing a new product, firms also need to determine an appropriate introduction time and production-sales policy. Starting sales without building an initial inventory (a *myopic* policy) will lead to supply shortages if demand exceeds production capacity. Companies generally use a *build-up* policy and create initial inventory before launching the new product as a supply cushion, replacing the need for expensive and timely capacity expansions (Fig. 2). There are several examples where even companies with significant experience in successful new product launches faced tremendous losses due to incorrect decisions on these issues. In 1996, the demand for Tamagotchi™, the first virtual pet, rapidly grew beyond production capacity, leading to lost sales. Soon after the company (Bandai Co.) expanded their capacity in 1998, the demand started to decline, resulting in $123 million in after-tax losses (Higuchi and Troutt, 2004). In the case of PlayStation®3, Sony Electronics Inc. lost $1.8B in its game division and laid off 3% of its workforce due to demand over-estimation and excessive production and inventory costs (*Los Angeles Times*, June 7, 2007).

* Corresponding author.
E-mail address: anegahban@psu.edu (A. Negahban).

https://doi.org/10.1016/j.ijpe.2017.11.019
Received 27 June 2017; Received in revised form 20 November 2017; Accepted 22 November 2017
Available online 24 November 2017
0925-5273/

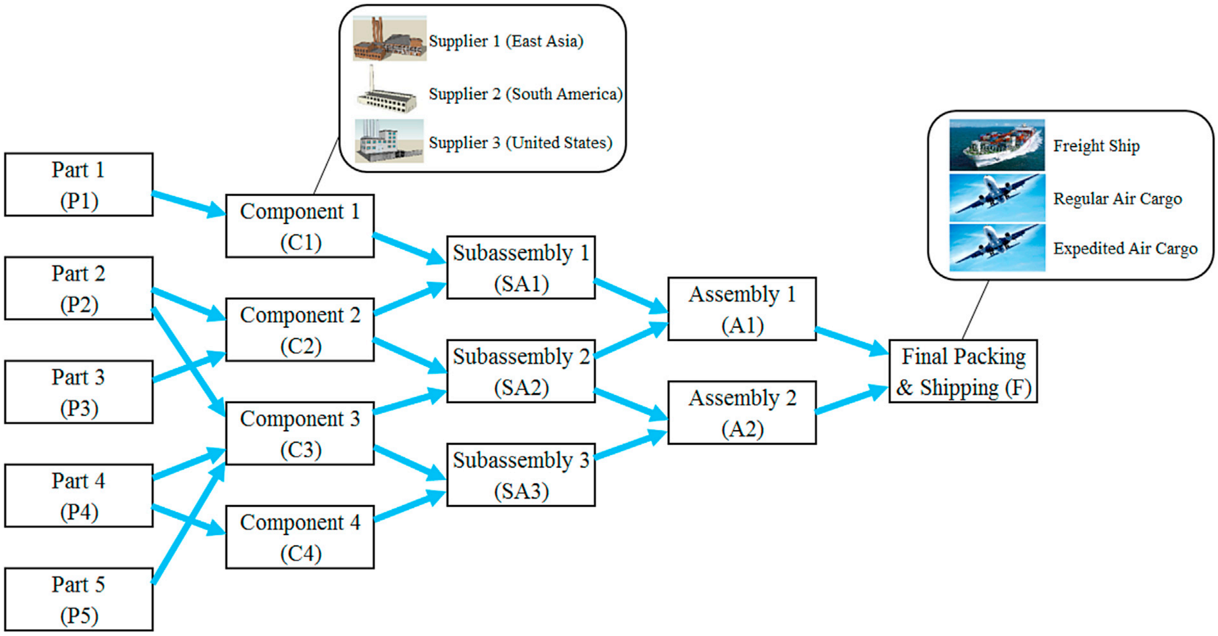

Fig. 1. Personal computer supply chain network adopted from Kilger et al. (2015) and Li and Amini (2012).

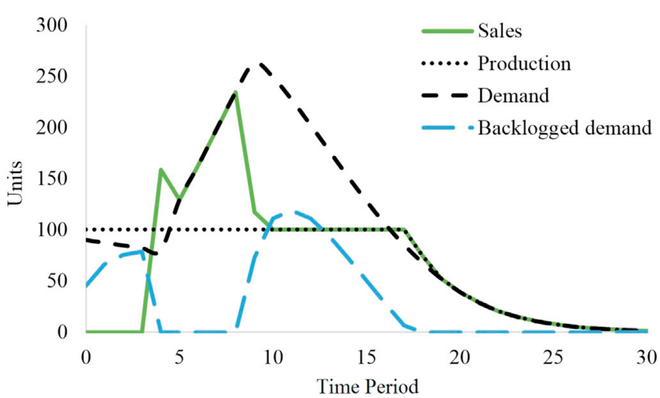

Fig. 2. An example of supply-constrained diffusion dynamics under a build-up policy with four periods of inventory build-up. The product is launched at the end of the build-up period at which point the firm starts to sell as many units as possible. The firm continues production at maximum capacity (100) until the demand starts to decline and falls below production capacity. Due to insufficient inventory, production cannot keep up with the demand resulting in backlogged demand and lost sales.

As a result, a flexible supply chain that can effectively adapt to the changing demand for a new product is crucial. This requires that the company monitors the demand dynamics and optimizes the supply chain configuration periodically, which may result in adding new suppliers and/or changing demand allocation among current suppliers for different production stages. These periodic reviews may also suggest adjusting pipeline and safety stock allocations for production stages over the next planning horizon (i.e., until the next review cycle). For example, during the 2009 fiscal year, Sony significantly reduced the total number of suppliers to increase its supply chain efficiency while still maintaining its general policy of multiple suppliers for most of the critical parts and components (Sony Corporation, 2009). While using multiple planning horizons can help avoid excessive production and inventory costs, there is a cost associated with making such modifications including contractual penalties, workforce training, and cost of acquiring new and/or additional equipment (Sucky, 2007; Porter, 1980; Friedl and Wagner, 2012; Lewis and Yildirim, 2005).

Motivated by the above, we propose a mixed-integer nonlinear programming (MINLP) model that integrates the diffusion and supply chain sides of this problem. The model allows for optimization of supply chain configuration over multiple planning horizons while considering multiple-sourcing and cost of modifying/switching suppliers. More specifically, we explore the following important research questions that the existing literature leaves unanswered:

1. How much can a firm benefit from adjusting the supply chain configuration for its new product from one planning horizon to another in response to the changing demand dynamics? More importantly, is the total profit an increasing function of the number of planning horizons?
2. Is it a good strategy to choose suppliers solely based on their direct cost added or lead time? How much and under what circumstances are myopic and build-up heuristic policies effective?
3. What is the inter-dependency between the number of build-up periods, number of planning horizons, and cost of changing the supply chain configuration?

The remainder of this paper is organized as follows. Section 2 presents a critical analysis of the related literature. The mathematical formulation of the proposed MINLP model is described in Section 3. A representative application of the model is provided in Section 4, and Section 5 presents the results of numerical experiments with the model. Finally, limitations and important implications for future research and practice are discussed in Section 6.

2. Literature review

This section presents a critical analysis of three related streams of research with the goal to identify the strengths and gaps in the existing studies and delineate the contributions of this paper.

2.1. Stream 1: production-sales policies for new products

This stream is related to the interface of marketing and operations management and mainly focuses on the inter-dependency between the demand and supply for new products (for an early study in this stream, see Jain et al. (1991)). These studies generally use an analytical method (e.g., optimal control theory or dynamic programming) or simulation,