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Supply chain configuration for diffusion of new products: An integrated optimization approach

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ABSTRACT

We develop an integrated/hybrid optimization model for configuring new products' supply chains while explicitly considering the impact of demand dynamics during new products' diffusion. The hybrid model simultaneously determines optimal production/sales plan and supply chain configuration. The production and sales plan provides decisions on the optimal timing to launch a new product, as well as the production and sales quantity in each planning period. The supply chain configuration provides optimal selection of options and safety stock level kept at each supply chain function. Extensive computational experiments on randomly generated testbed problems indicate that the hybrid modeling and solution approach significantly outperforms non-hybrid alternative modeling and solution approaches under various diffusion and supply chain topologies. We provide insights on optimal production/sales plan and supply chain configuration for new products during their diffusion process. Also, managerial implications relevant to effectiveness of the hybrid approach are discussed.

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1. Introduction

In this paper, we consider the scenario where a firm needs to configure its supply chain before launching a new product. To respond to customer demand efficiently, the firm's supply chain configuration encompasses decisions including selection of suppliers; manufacturing and transportation modes; as well as locations in supply chain network to place appropriate levels of safety stocks.

Under a fixed production and supply capacity in the intermediate term, the firm might be overwhelmed by potentially rapid growth of demand for the new product due to marketing activities and positive word-of-mouth. Examples include Apple's iPhone [1] and Nintendo's Wii [2], where both manufacturers were hit by the rapid growth of demand for these innovative products. Often, such an impact affects not only the manufacturer itself, but also its vendors and suppliers through the supply chain. Example includes Apple's PowerMac G4 [3], where Motorola, as the supplier of G4 chips, was not able to catch up with the rapid growth of demand for the popular computer. Another potential scenario for the firm is to experience a slow growth in demand for the new product and hence resulting in major financial risks. For example, initial sales of Sony's Playstation 2 (PS2) were more than ten times that of the original PS's introduction five years earlier [4]. However the launch of Playstation 3 (PS3) was not successful for Sony and hence resulted in \$1.8B annual loss in its game division and layoff of 3% of its workforce [5].

Manufacturers are often able to save inventory cost by not keeping any initial stock before launching the new product, but they (and related players in the supply chain) may suffer later when supplies of the new product are outpaced by the fast growth of demand. Often, the saving on inventory cost may not compensate the cost due to lost demand. On the other hand, when a firm experiences demand below expectation, the inventory cost of safety stocks located at different tiers of supply chain network has a negative effect on efficiency. Thus when launching a new product, efficiency in terms of cost and speed is not the only quality a successful supply chain can own. As noted by Lee [6], supply chains that fail to adapt to changes in market structure will not gain sustainable competitive advantage. These have motivated us to model marketing-supply chain interactions, and in particular, the interaction between new product's diffusion and the corresponding supply chain's configuration.

The dynamics of customer demand during diffusion of new products are well-captured by the classical Bass model [7]. Kumar and Swaminathan [8] and Ho et al. [9] have shown that the customer demand pattern during new product diffusion will affect the manufacturer's production planning decisions during the new product's lifetime. They extend the classical Bass model by considering production capacity of the firm, so that the demand of a new product may not be completely met due to the production capacity limit. Their model is used to find optimal

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production and sales plans that maximize profit during the new product's lifetime, spanning from one to two years. They find that when supply constraint is present, the rapid growth of customer demand during diffusion may motivate manufacturer to buildup initial inventory and delay launching of the new product. We call their model the new product diffusion (NPD) model in the sequel. The NPD model focuses on the interactions between manufacturing and marketing/sales decisions *within* a firm by assuming a fixed per-unit product cost, but ignores other functions of the firm's supply chain like procurement, sourcing, assembly and distribution.

Graves and Willems [10] proposed a model optimizing the supply chain configuration for a new product, which we call the supply chain configuration (SCC) model. In this model, a firm selects options for each function (components, parts, or processes required) in the supply chain to minimize the system-wide total supply chain cost. Available options often differ in lead time and direct cost added. For instance, parts and raw materials can be purchased from different suppliers. Goods can be shipped via regular ground shipping or next day delivery. The SCC model also allows coordination among supply chain players by optimally determining their inbound and outbound service times, thus the inventory positioning through the supply chain. New product demand is assumed to be known in the form of mean and standard deviation for the entire planning horizon (usually 9 months–1 year). Because demand is exogenously given, the question of how the demand trajectory during new product diffusion will impact supply chain configuration is not addressed by the SCC model.

The problems addressed by the NPD and SCC models are closely related. Both problems are *tactical* in nature. During the new product's life cycle, the firm's production and sales plan is only part of the big picture. Given the expanded complexity and scope of modern supply chains, it is rare to have a single firm being involved through all stages of sourcing, manufacturing, assembly, transportation, warehousing and delivery. Thus the firm is facing more important and wider scope of decisions on how to configure its entire supply chain to allow products as well as the required parts and components (described by the new product's bill-of-materials or BOM) to be sourced, manufactured and delivered in an efficient and responsive manner.

Therefore, there is merit in developing an integrated optimization model to study the optimal supply chain configuration decision in concert with dynamic process of new product diffusion. On one hand, the demand pattern (in terms of mean and variation) during new product diffusion has an explicit impact on supply chain configuration. Specifically, the mean customer demand serves as the external demand to be satisfied by the supply chain network, and the variation of demand directly impacts the amount of safety stock to carry (or inventory positioning) through the supply chain. On the other hand, the configuration of supply chain may in turn affect the optimal diffusion pattern of the new product. This is due to the fact that in the general supply chain settings, the per-unit cost of product should be calculated as an accumulative cost due to selection of suppliers/vendors and manufacturing/transportation modes through different supply chain stages such as sourcing, assembly, transportation, etc. This implies that the per-unit cost assumed to be constant in manufacturing planning models during diffusion, as in [8], can be extended and generalized to the so-called unit manufacturing cost (UMC) determined through configuring the corresponding supply chain [10].

In this study, we present a hybrid model to configure a new product's supply chain by considering the dynamics of diffusion process through the product life cycle. Both the demand/supply pattern and unit-product cost are endogenously determined in one model, as opposed to being exogenous as assumed in the separate models. Our model offers a decision support tool for simultaneously optimizing an innovator's production planning in a multi-period setting and supply chain configuration. It also provides a modeling framework to design a supply chain which is not only cost efficient, but also adaptive to the changing market demand during new products' lifetime.

As we will show, solutions that optimize supply chain performance from either the NPD aspect or the SCC point of view alone would not obtain optimal solutions. Lower supply chain configuration cost is often achieved by a *myopic policy*, i.e. selling as much as possible in each time period. This leads to less variation of the realized demand, thus less safety stock. However, such myopic policy may perform poorly from the diffusion perspective due to loss of demand. On the other hand, a *buildup policy*, i.e. delaying the launch of the new product and building some initial inventory, may generate higher sales revenue from the diffusion perspective; but too many buildup periods may lead to increased amount of safety stocks and hence increase supply chain configuration cost. Determining the optimal number of buildup periods will not be an intuitive task without the aid of an integrative optimization model in which both supply chain configuration decisions and new product diffusion outcomes are simultaneously considered.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature. Section 3 presents the integrated model. The computational experimental study and results are presented in Section 4. Section 5 draws conclusions and suggests future research directions.

2. Related literature

Our work is related to the research literature of supply chain configuration design in operations management and new product diffusion in marketing. In this section, we provide a review of the supply chain configuration and new product diffusion process literature. Also, we discuss the merit and objectives of the current study.

Supply chain configuration design is traditionally understood as determining the optimal manufacturing and distribution network of a firm at the strategic level (see, e.g., [11,12]). Such strategic decision problems focus on designing physical supply chain networks and often have a long-term impact for the firm from 5 to 10 years. In today's fast changing and competitive business environment, however, a new product's life cycle (often around or less than 1 year) is much shorter than the scale of strategic planning horizon. When designing supply chain for new products, it is critical that the supply chain adapts to the changing environment in terms of demand, lead time and cost in the intermediate run. Thus the supply chain configuration problem, addressed in this paper, focuses on tactical level decisions with a planning horizon that matches a new product's life cycle. Such tactical supply chain configuration problems are able to model all echelons in the supply chain and optimize the system-wide supply chain performance [10], as opposed to optimizing two or three echelons in strategic network design problems.

The tactical supply chain configuration problem on multi-echelon supply chains has its root in the so-called inventory positioning problem, which studies where in the supply chain to keep safety stock. Early models on inventory positioning, e.g., [13–16], optimize safety stock levels for an existing supply chain by assuming that the option chosen at each supply chain function is fixed.

Graves and Willems [10] developed a model that simultaneously determines the safety stock placement and option