Computers & Industrial Engineering 78 (2014) 44–54

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

Modeling risk in a Design for Supply Chain problem

Erin Claypool [a,*], Bryan A. Norman [a], Kim LaScola Needy [b]

[a] Department of Industrial Engineering, University of Pittsburgh, Pittsburgh, PA 15261, USA
[b] Department of Industrial Engineering, University of Arkansas, Fayetteville, AR 72701, USA

ARTICLE INFO

Article history:
Received 9 January 2014
Received in revised form 5 August 2014
Accepted 29 September 2014
Available online 8 October 2014

Keywords:
Design for Supply Chain
Supplier Selection
New Product Development
Risk
MIP
Simulation

ABSTRACT

The objective of Design for Supply Chain (DFSC) is to design a supply chain in parallel to designing a new product. Risk is an inherent element of this process. Although supply chain risk models and product development risk models are available, there are few models that consider the combined effect of risk to product development and the supply chain. This gap is filled by the development of a DFSC and risk model that looks at design, supply chain and risk concurrently. The model consists of two components. First, a Mixed Integer Programming (MIP) model makes the DFSC decisions while simultaneously considering time-to-market risk, supplier reliability risk and strategic exposure risk. The results from the MIP are then used in the second model component which is a discrete event simulation. The simulation tests the robustness of the MIP solution for supplier capacity risk and demand risk. When a decision maker is potentially facing either of these risks the simulation shows whether it is best to use an alternative solution or proceed with the MIP solution. The model provides analytical results, but also allows decision makers to use their own judgment to select the best option for overall profitability. In conclusion, testing shows that risk mitigation strategies can and should be determined from the DFSC and risk model, but that they will be dependent on the specific design problem being solved.

1. Introduction

In today's highly competitive and globalized market, manufacturing firms are placing an emphasis on efficiency and cost effectiveness. One method for cutting costs and improving efficiency that is gaining popularity is a concept known as Design for Supply Chain (DFSC). The objective of this methodology is to design the supply chain in parallel to designing a new product. Traditionally, the supply chain is designed after the product design phase has been completed, which often results in a longer design cycle time and sub-optimal overall product profitability. It has been shown that significant productivity improvements and cost reductions can be achieved by collaborating with the supply chain engineers early in the design process. For example, in the first 4 years after implementing Design for Supply Chain Management at Digital Equipment Corporation, they realized a cost savings of approximately $1 billion. These savings were realized through simpler, streamlined supply chain and product designs, more efficient and effective planning techniques and improved cooperation and planning between their twelve plants (Arntzen, Brown, Harrison, & Trafton, 1995).

Regardless of the method used to cut costs and improve efficiencies, all companies face risk. This research is focused on the incorporation of risk management into the DFSC methodology. Risk has been defined by Lowrance (1976) as a "measure of the probability and severity of adverse effects." Risk management is a technique that has been used for centuries. Many analytical models have been developed, and are available, to analyze supply chain risks, and models have also been created to evaluate risk in the New Product Development (NPD) process (Ahmadi & Wang, 1999; Ghodsypour & O'Brien, 2001; Nembhard, Shi, & Aktan, 2005). However, there is room for improvement with these models and tools. Supply chain risk models and NPD risk models are available, but there are few models that integrate both aspects simultaneously.

The development of a hybrid DFSC and risk model, which is achieved with this research, fills a gap in the current literature. Designing a new product and its corresponding supply chain consists of multiple phases and decisions (Dym & Little, 1999; Govil & Proth, 2002), all of which cannot be adequately addressed in this research. The scope of this research is, therefore, limited to the detailed design phase of the product design process and only the supplier selection component of supply chain design. This research is also a significant extension of Gokhan's dissertation titled

* Corresponding author at: 1048 Benedum Hall, 3700 O'Hara Street, Pittsburgh, PA 15261, USA. Tel.: +1 412 624 9830.
E-mail addresses: eagst28@pitt.edu (E. Claypool), banorman@pitt.edu (B.A. Norman), kneedy@uark.edu (K.L. Needy).

http://dx.doi.org/10.1016/j.cie.2014.09.026
0360-8352/© 2014 Elsevier Ltd. All rights reserved.

"Development of a Simultaneous Design for Supply Chain Process for the Optimization of the Product Design and Supply Chain Configuration Problem" (Gokhan, 2007).

The creation of a hybrid DFSC and risk model is essential for companies that are designing and manufacturing new products. A survey by Accenture, found that 110 of 151 U.S. supply chain executives said that their companies faced supply chain disruptions in the past 5 years (Singhal, 2008). Similarly, most new products never reach the market, and those that do suffer failure rates around 25–45% (Cooper, 2001). Therefore, for a company to actively compete in today's global economy it is very important to manage cost, quality, efficiency, and also risk. The development of this model makes an important contribution and is far from trivial, due to the number of risks under consideration, the uncertainty associated with the risks and the complexity of modeling risk.

The remainder of the paper is organized as follows: Section 2 contains a review of the related literature. Section 3 shows how the DFSC and risk model was developed. Section 4 includes computational results from the DFSC and risk model. Then, Section 5 concludes the paper and provides recommendations for future research in this subject area.

2. Literature review

Researchers and practitioners began to recognize the benefits of an integrated DFSC approach in the early nineties. The term Design for Supply Chain Management was first used in 1992, in an article by Lee and Billington (1992). They introduced the concept of Design for Supply Chain Management as an opportunity to improve the product design process.

Several years later, Lee and Sasser (1995) presented a case study of a DFSC implementation. In their study, Hewlett–Packard (HP) used a DFSC model on a new product line, to determine the optimal product differentiation point. The model included stochastic demand, lead time decisions, service level targets, and inventory, stockout, and shipment costs. Analytical solutions for different product life cycle phases, as well as for different design alternatives, were given. This study is especially interesting, because real data was used and the results were validated after the product was launched. A limitation of this work is that they did not incorporate the supplier selection decision.

Around the same time as the HP case study, Lee and Billington (1995) also reported on the evolution of Supply Chain Management models and practices at HP. These new practices were driven by high inventories and high customer dissatisfaction rates. Through this evolution HP developed a successful approach for modeling and optimizing the supply chain, which added distribution, market, and product specifications into their previous inventory modeling efforts. The reported benefits of their new models and practices include incorporating all related divisions of the company, key suppliers, and key customers into the SC design decisions and developing product-based supply chains.

Arntzen et al. (1995) conducted a DFSC analysis at Digital Equipment Corporation. Changes in the computer industry drove change in Digital Equipment Corporation's business, which led to this study and the development of their Global Supply Chain Model. The model included supply chain, manufacturing and logistics elements. The objective was to minimize cost and time. A Mixed Integer Linear Programming framework was used to model the problem and then a branch and bound algorithm was used to solve it. This model was used in the design of 20 new products and helped achieve a reported savings of $1 billion in 4 years with approximate unit production improvements around 500%. Limitations of the model include an assumption of fixed demand and an objective function limited to time and cost.

Fandal and Stammen (2004) presented a strategic Supply Chain Management model that incorporates the entire product life cycle from selecting a development program through recycling. It enabled designers to compare product life cycles, development and recycling strategies for different product alternatives. However, due to the size of this model, it could not be solved efficiently.

Graves and Willems (2005) did not explicitly create a DFSC model, but rather a supply chain decision model that took into consideration a product design which has already been selected. The model is solved with dynamic programming, modeling the supply chains as spanning trees. Validation of the model was achieved by performing a four-week case study at a Fortune 100 computer manufacturer.

Lamothe, Hadj-Hamou, and Aldanondo (2006) proposed a model that was used for a product family selection and supply chain network design problem. In this model each product family variant was associated with a different market segment. The demand in these market segments had to be satisfied by the associated product family or one that was better. The objective of the model was to minimize total supply chain cost. The main limitation of the model was its inability to directly relate product design with demand generation.

Sharifi, Ismail, and Reid (2006) presented a theoretical framework for operating in a DFSC environment. They also provided a case study, which proved that it is more effective to operate in a DFSC manner as opposed to designing the new product and supply chain separately. Zhang, Huang, and Rungtusanatham (2008) simultaneously optimized over variants of a product platform and the corresponding supply chain, using a MIP.

Yadav, Mishra, Kumar, and Tiwari (2011) include several aspects of the product design and supply chain design problem that were not previously considered. These include the plant location and capacity decision, shipping channels and product pricing. Their DFSC problem is solved using a Genetic Algorithm.

Shidpour, Shahrokhi, and Bernard (2013) uses a combination of multi-objective linear programming, Fuzzy Analytic Hierarchy Procedure (FAHP) and the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) to develop an integrated qualitative and quantitative decision procedure for selecting a design alternative, assembly process and suppliers.

Although there have been DFSC models developed as just described, they each have some limitations. The DFSC model presented in Gokhan (2007) attempted to create a model without the limitations of the previous research. It included manufacturing costs, customer satisfaction, demand generation, in-bound supply chain operation, and maximized profitability over the entire lifecycle of the product. However, Gokhan's model did not consider risk.

No studies were found that considered new product design, supply chain design and comprehensively analyzed all risk factors associated with each. However, some of the DFSC models examined earlier do take into consideration a few risk factors. For example, Lee and Sasser (1995) created a DFSC model, which HP used during the development of a new product. It was particularly important for the success of this product to determine the optimal product differentiation point, to avoid high inventory, inventory stockout and long lead times. These factors were included in the model, so that the risk of the selected product experiencing those issues was minimized.

The Global Supply Chain Model presented in Arntzen et al. (1995) includes duty considerations for international suppliers. By including this factor the risk of working with an international supplier is being modeled. However, the constraints in the model are not inclusive of all international business risks.

Graves and Willems (2005) created a supply chain design model for a product that has already been designed. They created a large designed experiment to test for several different factors that can be