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Multi-objective stochastic supply chain modeling to evaluate tradeoffs between profit and quality

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ABSTRACT

Many companies struggle with justifying the cost of quality within their supply chain. Outsourcing suppliers to countries such as China has become popular in recent years due to the fact it appears to be more profitable. These outsource decisions do not effectively determine the impacts of quality defects. In this paper we demonstrate a method for evaluating the systemic supply chain risk of poor quality. We introduce a multi-objective stochastic model that uses Six Sigma measures to evaluate financial risk. Results from modeling suggest quality, profit, and customer satisfaction can be evaluated.

1. Introduction

Many companies struggle with justifying the cost of quality within their supply chain. Outsourcing suppliers to countries such as China has become popular in recent years due to the fact it appears to be more profitable. However, what many companies fail to see is the cost associated with varying quality levels from their suppliers. In order to create a quality product, the company must address all aspects of the supply chain, including individual processes and supplier selection.

A supply chain (SC) can be expressed as the sum of parts involved in fulfilling a customer request (Chopra and Meindl, 2007). By this definition, a supply chain consists of suppliers, manufacturers, warehouses, retailers, transporters, and customers. The purpose of a supply chain analysis is to maximize an organization's profit in the process of generating value for the customer, namely maximizing the difference between the final product worth and the total cost expended by the supply chain to provide the product to the customer.

Many organizations emphasize quality as a means to stay competitive in the marketplace over the long run. They view having a reputation of high quality as representing future market share for new customers and maintaining market share for existing customers over their lifetime. Further, improving quality can provide long term financial savings, such as scrap and rework reduction. We associate these quality savings as long term savings that are difficult to quantify. One method to quantify quality is the initiative known as Six Sigma. The label "Six Sigma" originates from statistical terminology, wherein sigma (σ) represents standard deviation. The probability of falling within plus or minus six sigma on a normal curve is 0.9999966, which is more commonly represented as a defect rate of 3.4 parts per million (Yang and El-Haik, 2003). This level of quality is seen as the goal in most Six Sigma initiatives, but the terminology is also used to evaluate current levels below that, such as 4 Sigma representing a plant that has 6210 defects per million. The corresponding defective rates for each Sigma level are shown in Table 1 below.

In order for a supply chain to remain profitable, quality from suppliers must be considered on the decision making process. Competing strategies of increasing profit as opposed to increasing quality will require many tradeoffs. The purpose of this article is to model the tradeoffs and to identify situations that a decision maker can use to optimize the benefits of both.

2. Background

As various quality assurance methods are being developed and discarded, total quality management (TQM) through Six Sigma is becoming popular. The goal of TQM and Six Sigma is to identify the poor quality immediately during the production process, rather than spending time to inspect the finished product. The quality of the manufacturing process determines the quality of a finished product. In the supply chain it is not always possible to control the manufacturing process for incoming materials, especially for outside suppliers. In this instance, quality can only be measured by the percentage of defective goods received from the suppliers. In order to more effectively manage the supply

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Table 1
Sigma levels for parts per million defective.

Sigma level	Parts per million defective
1	691,462
2	308,538
3	66,807
4	6210
5	233
6	3.4

chain, companies must choose suppliers that will produce quality materials without a substantial price tag.

Supply chain management (SCM) is responsible for the optimization of the flow of products between the various levels of the supply chain and for minimizing the total cost of these operations. This term SCM is a unification of a series of concepts about integrated business planning that are joined together by the advances in information technology (IT) (Shapiro, 2007). Despite the IT advances, many companies have not completely taken advantage of computing power to make cost effective decisions.

Competition between companies, more demanding customers, and reduced profit margins make the success of a company more challenging. In this context, SCM became a very important practice for companies that not only want to stay in business but also have their results optimized and meet the clients' expectations. Responsiveness in the supply chain has gained importance and it is a trend that will dictate future decisions regarding supply chain design.

It can be seen that SCM plays and will continue to play an active role in successful companies' routines. Literature about supply chain design is extensive and diverse. The common issue addressed in similar literature is to optimize the supply chain while the customer's demand is satisfied at some level.

While existing supply chain decision levels have been divided in strategic, tactical, and operational levels (Anthony, 1965), the focus of this research addressed strategic and tactical aspects of the supply chain. The main difference between these levels is that strategic decisions are concerned with the supply chain topology, such as which nodes are going to be utilized, represented by binary variables. Tactical decisions usually assume that the supply chain topology is already given and its main purpose is to optimize production rates, utilization, vendor selection, and resource allocation. Several works have been published about the optimization of supply chains. A very useful literature review and critique is presented by Meixell and Gargeya (2005).

2.1. Stochastic optimization in supply chains

The use of uncertainty models in supply chain management problems is a natural extension of the traditional deterministic approach. This happens due to the fact that most problems faced by companies have as a characteristic some degree of uncertainty. Thus, the assumptions that all the parameters used in modeling are deterministic is not realistic, especially when considering elements that are in most cases beyond the scope of the company, such as demand, prices, and efficiency rates. In order to address this need, some approaches introduce stochastic elements in the model. Some use system dynamics and control theory to model uncertainty. Perea et al. (2000) and Vlachos et al. (2007), for example, utilize traditional control theory, whereas others utilize model predictive control (MPC) like Perea-López et al. (2003). Haralambos et al. (2008) discuss the characteristics of this approach and give a literature review of the subject.

The largest category of uncertainty models addresses the uncertainty of variables by assigning statistical distributions. Works such as MirHassani et al. (1999) and Ahmed et al. (2000a) address the production planning problem under uncertainty. A common point in those works is that they only analyze tactical decisions and do not account for the strategic level decision formulation.

More recent works approach the tactical and strategic decision making by the use of two stage stochastic integer programming in most cases. MirHassani et al. (1999) uses this strategy and scenario analysis of solutions with Benders' decomposition in a multi-period resource allocation model. Ahmed et al. (2000) approached the capacity expansion of a supply chain problem by using a multi-stage stochastic programming formulation with a scenario tree to model the evolution of uncertainty. In Gupta and Maranas (2000, 2003) and Tsiakis et al. (2001), the authors also use two-stage stochastic programming to make tactical and strategic decisions in the supply chain under demand uncertainty. Alonso-Ayuso et al. (2003) made use of a Branch and Fix Coordination algorithm to solve the stochastic integer programming problem of a two stage supply chain problem. Blackhurst et al. (2004) uses a network-based approach to model uncertainty in a supply chain. Ryu et al. (2004) uses bi-level programming and parametric programming to solve a supply chain resource allocation problem under demand uncertainty.

2.2. Multi-objective optimization and supplier selection in supply chains

Most of the existing literature is focused on the optimization of only one objective function, usually cost or profit, and other important factors such as quality and supplier selection are left outside the analysis.

There are many techniques for multi-objective optimization such as the ε-constrained method, sequential optimization, weighted methods, and distance-based methods (Szidarovszky et al., 1986). Guillén et al. (2005) utilizes the ε-constrained method in order to optimize profit, demand satisfaction, and financial risk cost of a three echelon supply chain. Azaron et al. (2008) uses the goal attainment technique to optimize total cost, total cost variance, and financial risk cost of a three echelon supply chain. Chen et al. (2003) uses a two-phase fuzzy decision-making to optimize profit between the supply chain participants, customer service levels, and safe inventory level. In this paper, the utilized method is the ε-constrained in order to optimize the profit and quality objective function. This method provides a set of objectives that are Pareto efficient, thus forming a Pareto frontier (for more information on multi-objective stochastic programming, refer to Stancu-Minasian, 1984).

2.3. The cost of poor quality

Quality is a significant concern in the supply chain because of the historical problems that have come from supplier selection. The most common reasons quality assurance (QA) fails to adequately address these issues are: (1) the company outsourced to does not have its own QA team, and assumed that the client would complete this in-house, (2) the project had a very tight deadline and so QA testing was done rapidly or set aside to give development a priority, and (3) the vendor did not fully understand the system requirements, and so testing did not cover them (Singh, 2006). These and other reasons generate both the recall and product quality issues that make the news. It has also been shown that outsourcing poses a quality risk, on average (Gray et al., 2007).