Design of Six Sigma Supply Chains

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***Abstract*—Variability reduction and business-process synchronization are acknowledged as keys to achieving sharp and timely deliveries in supply-chain networks. In this paper, we introduce a new notion, which we call *six sigma supply chains* to describe and quantify supply chains with sharp and timely deliveries, and develop an innovative approach for designing such networks. The approach developed in this paper is founded on an intriguing connection between mechanical design tolerancing and supply-chain lead-time compression. We show that the design of six sigma supply chains can be formulated as a mathematical programming problem, opening up a rich new framework for studying supply-chain design optimization problems. To show the efficacy of the notion and the design methodology, we focus on a design optimization problem, which we call the inventory optimization (IOPT) problem. Given a multistage supply-chain network, the IOPT problem seeks to find optimal allocation of lead time variabilities and inventories to individual stages, so as to achieve required levels of delivery performance in a cost-effective way. We formulate and solve the IOPT problem for a four-stage make-to-order liquid petroleum gas supply chain. The solution of the problem offers rich insights into inventory-service level tradeoffs in supply-chain networks and proves the potential of the new approach presented in this paper.**

***Note to Practitioners*—This paper builds a bridge between mechanical design tolerancing and supply-chain management. In particular, the paper explores the use of statistical tolerancing techniques in achieving outstanding delivery performance through variability reduction. Informally, a six sigma supply chain is that which delivers products within a customer specified delivery window, with at most 3.4 missed deliveries per million. The innovations in this paper are the following: 1) to define two performance metrics *delivery probability* and *delivery sharpness* to describe the precision and accuracy of deliveries, in terms of process capability indexes C_p,C_{pk}, and C_{pm}; 2) to formulate the supply-chain design optimization problem using the process capability indices; 3) to suggest an efficient solution procedure for the design optimization problem. The paper presents the case study of a two-echelon distribution network and using the framework developed in the paper shows the role of inventory in controlling lead time variability and achieving six sigma levels of delivery performance.**

***Index Terms*—Cycle time compression, delivery probability (DP), delivery sharpness (DS), Motorola six sigma (MSS) quality, process capability indexes (PCIs), process synchronization, six sigma supply chains, supply-chain lead time, variability reduction.**

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I. Introduction

Supply chains provide the backbone for manufacturing, service, and E-business companies. The supply-chain process is a complex, composite business process comprising a hierarchy of different levels of value-delivering business processes. Achieving superior delivery performance is the primary objective of any industry supply chain. Quick and timely deliveries entail high levels of synchronization among all business processes from sourcing to delivery. This in turn calls for variability reduction all along the supply chain. Variability reduction and business-process synchronization are therefore acknowledged as key to achieving superior levels of delivery performance in supply-chain networks.

A. Motivation

Lead times of individual business processes and the variabilities in the lead times are key determinants of end-to-end delivery performance in supply-chain networks. When the number of resources, operations, and organizations in a supply-chain increases, variability destroys synchronization among the individual processes, leading to poor delivery performance. On the other hand, by reducing variability all along the supply chain in an intelligent way, proper synchronization can be achieved among the constituent processes. This motivates us to explore variability reduction as a means to achieving outstanding delivery performance. We approach this problem in an innovative way by looking at a striking analogy from mechanical design tolerancing.

Variability reduction is a key idea in the statistical tolerancing approaches that are widely used in mechanical-design tolerancing [1]. A complex supply-chain network is much like a complex electromechanical assembly. Each individual business process in a given supply-chain process is analogous to an individual subassembly. Minimizing defective or out-of-date deliveries in supply chains can therefore be viewed as minimizing tolerancing defects in electromechanical assemblies. This analogy provides the motivation and foundation for this paper.

In statistical-design tolerancing, process capability indexes (PCIs) such as $C_p, C_{pk},$ and C_{pm} [2], [3] provide an elegant framework for describing the effects of variability. Best practices such as the Motorola six sigma (MSS) program [4] and Taguchi methods [5] have been extensively used in design tolerancing problem solving. In this paper, we use these popular approaches in a unifying way to address variability reduction, synchronization, and delivery performance improvement in supply-chain networks.

B. Contributions

The contribution of this paper is two fold. First, we recognize the key role of variability reduction and synchronization