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Economic selection of process mean for single-vendor single-buyer supply chain

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ABSTRACT

Process mean selection for a container-filling process is an important decision in a single-vendor single-buyer supply chain. Since the process mean determines the vendor's conforming and yield rates, it influences the vendor–buyer decisions regarding the production lot size and number of shipments delivered from the vendor to buyer. It follows, therefore, that these decisions should be determined simultaneously in order to control the supply chain total cost. In this paper, we develop a model that integrates the single-vendor single-buyer problem with the process mean selection problem. This integrated model allows the vendor to deliver the produced lot to buyer in number of unequal-sized shipments. Moreover, every outgoing item is inspected, and each item failing to meet a lower specification limit is reprocessed. Further, in order to study the benefits of using this integrated model, two baseline cases are developed. The first of which considers a hierarchical model where the vendor determines the process mean and schedules of production and shipment separately. This hierarchical model is used to show the impact of integrating the process mean selection with production/inventory decisions. The other baseline case is studied in the sensitivity analysis where the optimal solution for a given process is compared to the optimal solution when the variation in the process output is negligible. The integrated model is expected to lead to reduction in reprocessing cost, minimal loss to customer due to the deviation from the optimum target value, and consequently, providing better products at reduced cost for customers. Also, a solution procedure is devised to find the optimal solution for the proposed model and sensitivity analysis is conducted to investigate the effect of the model key parameters on the optimal solution.

1. Introduction

Regardless of how well-designed or maintained a manufacturing process is, there will always exist a certain amount of variation among produced items. This variability is usually due to cumulative effect of many small, essentially unavoidable causes. It may not be possible to completely eliminate variability, but quality control methods are effective in reducing variation and consequently, improving the quality of items (Montgomery, 2005). In the literature and practice of quality control, there exist many tools used to reduce variation in the output of a production process. One of these tools is the process targeting which is particularly utilized in container-filling processes (i.e., food, drug, and cosmetic industries) (Duffuaa and Siddiqui, 2003). Typically in these processes, the containers are filled with material and a lower specification limit is set on the amount of the material in a can (Roan et al., 2000). A filled can is classified as conforming if its amount of material is larger than or equal to the lower specification limit. Otherwise, the can is classified as a non-conforming item which would be sold at a reduced price, reprocessed or scrapped.

Process targeting has received a considerable attention from researchers as well as practitioners. It is critically important to industries which are governed by laws and regulations on the net content labeling (Kloos and Clark, 1981). Studies performed by federal agencies showed that it is a common practice used by many vendors to set a high process mean (filling amount) in order to conform to specifications, this strategy leads to a "give away" cost (Roan et al., 2000). However, very tight process setting will have less production cost, but at the expense of an increased cost of recycling and reprocessing (Al-Sultan and Pulak, 2000). Thus, process targeting is a trade-off between material cost and the cost associated with producing non-conforming items. Specifically, it deals with the determination of the optimum process mean to achieve some economical objectives such as maximizing profit or minimizing process cost.

Recently, researchers have developed models that integrate the targeting problem with inventory/production decisions (for instance, Gong et al., 1988; Al-Fawzan and Hariga, 2002; Roan et al., 2000; Williams et al., 2000; Hariga and Al-Fawzan, 2005). These models are appropriate to vendors who order raw material to produce an item, and directly satisfy the demand of end customers. However, rapidly changing markets forced companies to provide better products at reduced cost for customers with heightened

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expectations. As a result, companies are pushed towards not only integrating different decision processes within their borders but also closely collaborating with their customers and suppliers. With the growing focus on supply chain management, firms realize that inventories across the entire supply chain can be more efficiently managed through greater cooperation and better coordination (Ben-Daya et al., 2008).

In the supply chain management literature, the single-vendor single-buyer problem has received a lot of attention in recent years as it is the building block for the wider supply chain. The global supply chain can be very complex and link-by-link understanding of joint policies can be very useful (Ben-Daya et al., 2008). In the single-vendor single-buyer model, the vendor manufactures a product in lots and delivers the produced lot to a buyer in number of shipments. The objective of this model is to determine the production lot size and shipments schedule which minimize the total cost of the vendor–buyer system.

Traditionally, the process mean selection and production/inventory decisions are determined separately in the single-vendor single-buyer. However, the choice of process mean by the vendor affects the likelihood that a given produced item will be non-conforming. Thus, the process mean determines the production yield rate which, in turn, influences other important production and inventory decisions, in particular, vendor's production lot size and number of shipments delivered from the vendor to buyer. Evidently, these decisions are directly related to the total cost of the supply chain. Consequently, the process mean and vendor–buyer decisions should be determined jointly in order to control the total cost associated with the supply chain. This integration would lead to higher conforming and yield rates, reduction in scrap or reprocessing cost, minimal loss to customer due to the deviation from the optimum target value, as well as, and perhaps most importantly, providing better products at reduced cost for customers.

The purpose of this paper is to develop a mathematical model for jointly determining the optimal process mean, production lot size, and shipments schedule which minimize the average total cost of vendor–buyer supply chain. The proposed model allows the vendor to deliver the produced lot to buyer in number of unequal-sized shipments. Moreover, every outgoing item is inspected, and each item failing to meet a lower specification limit is reprocessed. Besides, the advantages of using the proposed model are explored by studying two baseline cases. The first of which considers a hierarchical model where the vendor determines the process mean in isolation of production and shipment schedules. This hierarchical model is used to show the effect of integrating the process targeting with production/inventory decisions. The other baseline case is illustrated in the sensitivity analysis where the optimal solution for a given process is compared to the optimal solution when the variation in the process output vanishes. Further, a solution procedure is devised to find the optimal solution and sensitivity analysis is conducted to investigate the effect of the model key parameters on the optimal solution.

The organization of the paper is as follows: literature review is discussed in the next section. The notation is introduced in Section 3 followed by problem statement and assumptions. In Section 5, modeling framework is presented. Vendor–buyer models with and without process targeting integration are developed in Sections 6 and 7, respectively. In Section 8, sensitivity analysis is conduct and Section 9 concludes the paper.

2. Literature review

In the past, many shipment policies have been proposed in literature for the single-vendor single-buyer problem. Goyal (1977) proposed a model based on a lot-for-lot policy with infinite production rate. Banerjee (1986) extended this model by considering finite production rate. An equal-sized shipments policy was developed by Goyal (1988) where the produced lot is dispatched to the buyer in shipments of equal size. Goyal (1995) considered a different shipment policy where the shipment size increases geometrically. Furthermore, Hill (1997) modified the model developed by Goyal (1995) by considering the geometric growth factor as a decision variable. Goyal and Nebebe (2000) considered a shipment policy where the first shipment is small and the following shipments are larger and of equal size. The optimal solution of the problem without any assumption regarding the shipment policy was found by Hill (1999). Moreover, Chang et al. (2004) investigated lead time and ordering cost reductions. They assumed that buyer lead time can be shortened with an extra crashing cost that depends on the lead time length to be reduced and the ordering lot size. Pan and Yang (2002) developed integrated inventory model with controllable lead time. Also, Ouyang et al. (2004) considered stochastic lead time and assumed that shortage during the lead time is allowed, and lead time can be reduced at an added cost. Hoque and Goyal (2006) developed a heuristic solution procedure to minimize the total cost of setup, inventory holding and lead time crashing for an integrated inventory system under controllable lead time between a vendor and a buyer. Further, Hill and Omar (2006) relaxed an assumption regarding holding costs. They allowed for decreasing holding costs down the supply chain. This model has been modified by Zhou and Wang (2007). They indicated that when the holding cost of the vendor is greater than that of the buyer, the optimal shipment policy consists of unequal-sized shipments with successive shipment sizes increasing by a fixed factor equal to the ratio of the production rate to the demand rate.

In all models above, it is assumed that the production process of the vendor has one setting for the mean and variation among products is neglected. However, for container-filling processes, the vendor can control the mean filling amount and the variation among items is not negligible on many occasions. Many researchers have addressed container-filling problem where the process mean is assumed to be constant during the production cycle. For example, Hunter and Kartha (1977), Bisgaard et al. (1984), Golhar (1987), Golhar and Pollock (1988) and Boucher and Jafari (1991). Other researchers including Gibra (1974), Arcelus and Banerjee (1985), Rahim and Banerjee (1988), Al-Sultan and Al-Fawzan (1997), among others have focused on the targeting problem where the process mean is assumed to deteriorate with time. Moreover, Rahim and Al-Sultan (2000) considered both the mean and variance of the process as decision variables in the targeting problem. They simultaneously determined the optimal target mean and target variance. Shao et al. (2000) developed strategies for determining the optimal process mean for industrial processes when rejected goods can be held and sold to other customers in the same primary market at a later time. Further, Lee and Elsayed (2002) determined the optimum process mean and screening limits of a surrogate variable associated with product quality under a two-stage screening procedure. Recently, integrating inventory/production decisions with targeting problem has received significant attention, for instance, Gong et al. (1988) integrated inventory issues and targeting the process mean. They assumed that the process mean is constant during the production cycle. Al-Fawzan and Hariga (2002) extended this integrated model to the case where the process mean is time dependent. Furthermore, Roan et al. (2000) incorporated the issues associated with production run size and raw material procurement policy into the targeting problem. Also, Williams et al. (2000) examined process improvement alternatives for a container-filling process. They considered reducing the process setup cost, reducing the frequency of the out-of-control signals and reducing the process variation. Moreover, Hariga and Al-Fawzan (2005) determined simultaneously the optimal production cycle