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Loss-based quality costs and inventory planning: General models and insights

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Abstract

In this paper, we examine a joint lot-sizing and process investment problem with random yield and backorders. We allow for inspection and develop stochastic models which provide the optimal inspection and lot-sizing policy as well as the optimal process investment for variance reduction. The process quality loss profile around the target is captured via a modification of the Reflected Normal loss function. We conduct numerical experiments assuming that the proportion of defectives follows a Uniform distribution while the process quality characteristic follows either a Normal or Uniform distribution. We also develop closed-form solutions that depend on at most the first two moments of any general probability distribution of defective units and which allow us to examine the nature of optimal policies. We demonstrate via numerical experiments the value of our integrated approach for jointly determining optimal inventory, inspection, and investment policies. Overall, our models and analyses provide some interesting insights into this reasonably complex inventory-quality problem and open up several avenues for future work in this area.

Keywords: Inventory; Stochastic models; Process improvement; Loss functions; Yield uncertainty

1. Introduction and literature

In this paper, we address an inspection, inventory planning and process investment problem when process yield is random and backorders are permitted. Our work contributes to the extant literature and practice in several ways. We consider the proportion of defective units to be random, with the probability distribution of defective units being parametrically dependent upon the process investment. Second, we allow for backorders in the inventory policy thereby making our models more practical compared to earlier work. We apply a modified Reflected Normal loss function to the lot-sizing problem and demonstrate that it serves as a better alternative to Taguchi's loss function in the context of joint lot-sizing, inspection, and process investment. To the best of our knowledge, ours is the first study to develop an integrated approach for lot-sizing, inspection

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and process investment within a non-traditional quality loss framework while considering yield uncertainty and backorders. We demonstrate through numerical experiments, the value of our integrated approach as compared to a sequential approach wherein inventory-inspection and investment policies are determined separately. Finally, our contribution also lies in understanding the complex interaction between production, inventory, investment and quality in a fairly inclusive and realistic setting and demonstrating some of this complexity via rigorous analytical results.

Several studies in recent years have investigated process investment and process set-up cost/time reduction. One of the common goals of this area of research has been to study the resulting improvement in process quality as measured using traditional quality cost measures. Some seminal papers in this area include for example, Porteus (1986), Chand (1989) and Fine and Porteus (1989). In the past decade or so, Genichi Taguchi's alternative approach to measuring quality costs and consequently process quality improvement, has rekindled the interest in process improvement for researchers and practitioners alike. Taguchi's quality philosophy states that there is a cost for any finite variability in a process quality characteristic. Commonly referred to as *Taguchi's Loss*, this cost spills over to consumers as maintenance/repair costs, to manufacturers as warranty/scrap costs and to society as pollution/environmental costs (Taguchi and Clausing, 1990). A number of authors have looked at applications of Taguchi's quality cost ideas to process improvement and production planning. For example Ganeshan et al. (2001) develop an inventory planning model. Their model jointly provides the optimal investment for reducing process variance and the optimal lot size. According to Ganeshan et al., better operating policies are obtained by joint consideration of investment, set-up and holding costs in conjunction with reject costs and Taguchi's loss costs. Another study by Mukhopadhyay and Chakraborty (1995) determines the optimal process variance under Taguchi's loss. In the study by Mukhopadhyay and Chakraborty, the process quality characteristic follows either a Uniform or Normal distribution. Their model utilizes the *Taguchi* quadratic loss function for modeling Taguchi's loss and also contains reject costs and the cost incurred for variance reduction. In a more recent study, Kulkarni and Prybutok (2004), study an application of a modified form of the *Reflected Normal* loss function originally introduced by Spiring (1993). They show how this alternative to the widely recognized Taguchi quadratic loss function applies in the context of process investment and improvement. Kulkarni and Prybutok's findings indicate that the choice of loss function is driven by the distribution of quality losses around the process target and that although the numerical values of the optimal investment level are dependent upon the process probability distribution, the overall behavior of optimal investment levels is independent of the underlying process distribution. Although these papers study one or a combination of, lot-sizing, investment in process quality and non-traditional measurement of quality loss when a proportion of the units produced are defective, they do not address inspection policies in order to identify defective units. Also, none of these papers account for backorders when addressing a lot-sizing problem and more importantly they do not consider process yield to be random.

Kanyamibwa and Ord (2000) develop policies for optimally monitoring a production process. They assume that the process is inspected at regular intervals and is either continued or adjusted. Kanyamibwa and Ord define the total loss to be the sum of the loss due to variability and the loss due to sampling and inspection. They utilize a form of the Taguchi loss function. They however do not explicitly consider process investment for variance reduction and quality improvement. Gerchak and Parlar (1990) jointly determine yield variability and lot sizes in a continuous-time EOQ model. They assume that yield variability can be reduced through investments. Some other papers which jointly model quality control and inventory policy are Lee and Rosenblatt (1988), Porteus and Angelus (1997) and Grosfeld-Nir et al. (2000). For an excellent review of the literature on lot-sizing with random yields, the reader is referred to Yano and Lee (1995) and to Godinho and Fernandes (2003), for a classification scheme for papers which jointly consider production and quality control.

In one of the early studies on joint lot-sizing and inspection policies, Lee and Rosenblatt (1985) jointly determine the lot size and fraction to inspect in an EOQ model. Zhang and Gerchak (1990) extend the work of Lee and Rosenblatt (1985) by allowing for yield variability and treat the number of defectives in an inspected sub-lot to be random. This makes Zhang and Gerchak's joint lot-sizing and inspection model complex but at the same time more realistic. Zhang and Gerchak do not consider backorders, process investment or loss-based quality costs. They develop several important and interesting insights into the nature of optimal policies with and without replacement of defective units. Their detailed and insightful analysis provides an inspiration for future work in the area, such as this paper.