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Process improvement for a container-filling process with random shifts

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Abstract

In this paper, we study the efficacy of alternative process improvement strategies for a container-filling production process. Three types of improvement actions to modify process parameters are considered: reducing the process setup cost, reducing the arrival rate of the out-of-control state, and reducing the process variance. It is assumed that these process parameters can be changed with a one-time investment. The concept of a planning horizon is introduced as a means for modeling the investment decision and corresponding process improvement benefit. Models are formulated to determine the optimal process improvement and production parameters that minimize the unit time expected cost across a given planning horizon. Numerical analysis is used to examine relationships among the optimal investment strategy, production policy, and length of the planning horizon.

Keywords: Quality; Process improvement; Process mean; Process optimization

1. Introduction

In response to increasing competitive pressures and demands for greater quality conformance, manufacturers have been motivated to continually improve their production processes [1]. A wide variety of methods for improving production processes have been proposed to ensure that manufactured products meet quality requirements while minimizing the consumption of resources [2]. In the academic literature, models have been developed to demonstrate and to evaluate the benefits of such process improvements.

In the inventory control literature, the focus has been on the benefits attendant to set up cost reduction. For example, Porteus [3] and Rosenblatt and Lee [4] assess the relationship between product quality and lot size. Porteus considers the Economic Order Quantity (EOQ) model and assumes that the process has two performance states: in-control and out-of-control. The process starts from the in-control state and may shift to the out-of-control state randomly over time. Rosenblatt and Lee consider a similar, but more complex situation, in which the process state may follow linear or exponential deterioration. The general conclusion from these analyses is that a smaller lot size results

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in better lot quality (i.e., a lower lot nonconforming rate). Furthermore, a smaller lot size can be economical if the setup (or ordering) cost can be reduced by a one-time investment. Porteus' model has been generalized by Fine and Porteus [5] to permit multiple small investments in setup cost reduction; by Keller and Noori [6] to permit a random lead time; and by Gong et al. [7] to permit multiple process states. Zangwill [8] considers these issues in the context of dynamic lot sizing problem.

In the quality control literature, process improvement is generally viewed as reduction in process variation [9]. Two sources of process variation have been identified. The first is variability in raw materials, labor, equipment, and other environmental factors that may result in variation among the items produced by the process. The second relates to assignable causes which result in the process shifting to an out-of-control state(s).

The effects of process variation on process performance have been investigated numerically in many studies (see, for example, [10]). Recently, two analytical studies have reported on the effects of process variance reduction in the context of a container-filling operation. Golhar and Pollock [11] study the cost savings from process variance reduction when the process under consideration is assumed to be stable. Al-Sultan and Al-Fawzan [12] extend the model to a process for which the mean is subject to random linear drifts.

With regard to reducing the arrival rate of the out-of-control state(s), Fine [13] has proposed the concept of quality learning. The basic notion is that the producer can extend the time the process remains in control by investigating and learning from the causes of out-of-control occurrences. Tapiero [14] has proposed a similar but more complex model. Gong et al. [7] use a Markov model to study the benefits of reducing the possibility of the process moving to a worsened performance state.

In this paper, three types of process improvement actions for a container-filling operation are investigated: (1) reducing the process setup cost, (2) reducing the arrival rate of the out-of-control state(s), and (3) reducing the variation inherent in the process. The traditional dilemma for a container-filling process is the determination of the appropriate process mean. Consider a container-filling process with a lower product specification limit. It is assumed that items produced with contents below the lower specification limit are considered nonconforming and cannot be shipped to customers (we assume nonconforming items are identified and purged by automatic inspection). To reduce the likelihood of nonconforming production, the process mean may be set at some higher level. This action, however, results in an increase in material cost because the average amount dispensed into the containers has increased. Given this tradeoff, the producer must establish the process mean either to minimize production and material costs or to maximize net revenues of salable product.

The problem of determining the process mean has been studied extensively for stable processes under alternative revenue functions, rework schemes, capacity constraints, inventory structures, and inspection methods. Examples include Bettes [15], Hunter and Kartha [16], Nelson [17], Carlsson [18], Bisgaard et al. [19], Golhar and Pollock [20], Schmidt and Pfeifer [21], Boucher and Jafari [22], Al-Sultan [23], Pulak and Al-Sultan [24], and Tang and Lo [25], Roan et al. [10], Liu et al. [26], and Gong et al. [27].

Studies of unstable processes have primarily focused on drifts or shifts of the process mean and/or process variance during the course of production. A drift in the process mean over time may occur when a critical tool wears or when a spray nozzle gradually clogs. Shifts may occur because of a sudden voltage surge or power failure [28]; moreover, shifts may be deterministic or random in nature. Models that consider drifts include, for example, Gibra [29], Taha [30], Arcelus and Banerjee [31], Rahim and Banerjee [32], and Schneider et al. [33]. Arcelus et al. [34] consider shifts in both process mean and variance. Rahim and Lashkari [28] examine the situation in which the process is subject to both shifts and drifts. Reviews of this literature can be found in Tang and Tang [35], Al-Sultan and Rahim [36] and Rahim and Al-Sultan [37].

This paper is organized as follows. In Section 2, we introduce the assumptions, formulate a basic model and develop a solution procedure. In Section 3, we discuss the three types of process improvements, and present a numerical analysis for studying the relationships among the optimal investment