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The cost minimization and manpower deployment to SPC in a multistage manufacturing system

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Abstract

This article proposes an algorithm for deploying manpower to a statistical process control (SPC) system that monitors a multistage manufacturing system. The algorithm minimizes the expected total cost by optimizing the amount of allocated manpower in the SPC system (referred to as an M-SPC system), as well as the sample sizes, sampling intervals and control limits of the control charts. It also takes into account the probability distribution of the random process shifts at each process stage. Numerical studies show that the M-SPC system can reduce the total cost by about 75 percent, on average, compared to the traditional SPC system. It is also found that, in most of the traditional SPC systems, the allocated amount of manpower is far less than needed. This implies that the total cost can be significantly reduced with more manpower. Furthermore, the M-SPC system can be utilized and understood as easily as the traditional SPC system by shop floor operators. Some useful guidelines are provided to aid users in allocating the appropriate amount of manpower to different systems.

Keywords: Quality control; Control chart; Statistical process control; Multistage manufacturing system; Manpower deployment; Loss function

1. Introduction

The design algorithms of the control charts have been developed from two perspectives in the last several decades, namely, the statistical designs (Page, 1954; Keats et al., 1995; Prabhu et al., 1997; Costa, 1999; Wu and Spedding, 2000; Magalhães et al., 2006; Liu et al., 2006) and the economic designs (Duncan, 1956; Montgomery, 1986; Lorenzen and Vance, 1986; Castillo and Montgomery, 1996; Rahim and Costa, 2000; Al-Oraini and Rahim, 2002; Ohta et al., 2002; Yang and Rahim, 2005). A statistical design minimizes the out-of-control average time to signal (ATS) (i.e. the average time required to signal a process shift after it has occurred). For example, Costa (1999) developed the $\bar{X}$ and R charts with variable sample sizes and sampling intervals for speeding the detection of mean and variance shifts. However, the statistical designs do not directly measure the cost associated with the statistical process control (SPC) system. In contrast, an economic design aims to minimize the

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cost associated with the implementation of SPC. Duncan (1956) first proposed the economic design of the $\bar{X}$ control chart. Montgomery (1980) presented a literature survey for the early works in economic chart designs. Lorenzen and Vance (1986) developed a unified approach for the economic designs of the control charts. Rahim and Costa (2000) dealt with the economic design of the joint $\bar{X}$ and R charts in which the occurrence times of assignable causes follow a Weibull distribution with increasing failure rate. Ohta et al. (2002) proposed a similar economic model for the selection of parameters of time-varying charts.

A main objective of implementing SPC is to minimize the total cost (C_{total}), including quality cost (C_{quality}) due to poor quality (Besterfield et al., 1995) and manpower cost (C_{man}) for implementing the SPC system. Manpower (M) is a vital factor to the total cost. If M is small, manpower cost C_{man} is small; but manpower shortage may result in a large out-of-control ATS and, hence, a large quality cost C_{quality}. Conversely, if M is large, C_{man} is large; but C_{quality} may be substantially reduced as increased manpower allows the use of large sample size and/or frequent sampling, resulting in the prompt signal of out-of-control cases. Since these two components (C_{man} and C_{quality}) of C_{total} change in opposite directions with the change of manpower M, logically, there is an optimal value of M that minimizes C_{total}. Despite the importance of manpower to the total cost, little research has been done on its deployment to an SPC system. Only recently, Wu et al. (2006) studied the deployment of manpower to a single $\bar{X}$ chart.

The fabrication of a product usually goes through several stages in series. In this article, it is assumed that each stage has either a single stream or a few identical streams in parallel. The integration of all the stages constitutes a *manufacturing system*. For example, in the manufacturing of a mechanical part, each stage usually pertains to the machining of a dimension. Some of the dimensions are critical to the overall quality of the product and, therefore, control charts are required to monitor the corresponding process stages.

The literature on the design of the SPC systems that monitor multistage manufacturing systems is still limited. Woodall and Ncube (1985) investigated the multivariate CUSUM procedures and defined the out-of-control condition for a system comprising several charts. If each variable is considered as the quality characteristic in a stage, the method may be used to monitor the multistage system. Peters and Williams (1987) developed a control scheme for a three-stage manufacturing system based on a lost-cost model. Williams and Peters (1989) presented an np-control scheme integrated within a multistage production process. Hawkins (1993) discussed multivariate quality control based on regression-adjusted variables to make controls more effective than those based on variables individually. Wade and Woodall (1993) and Ding et al. (2002) published several papers studying the multistage processes and the diagnosis problems. Zantek et al. (2002) used quality linkages between the process stages to measure the effect of each stage on the output quality of subsequent stages of a multistage system and presented an economic model to aid the decision-making on the amount of investment in process quality improvement. Recently, Wu et al. (2004) and Lam et al. (2005) developed two statistical design algorithms for optimizing control limits and/or sample sizes and sampling intervals of the charts in a multistage SPC system in order to minimize the system ATS. However, these methods neither optimize the allocated manpower nor minimize the SPC cost. The manpower is fixed as a specification.

This article proposes an economic M-SPC system that optimizes the amount of manpower for the operation of the multistage SPC systems. The objective is to minimize the total SPC cost in the whole system. The M-SPC system consists of multiple control charts, each monitoring a critical stage in a multistage manufacturing system.

In this study, a *process* means the only stream in a single-stream stage or one stream in a multi-stream stage. Let s be the number of stages in series and g_i be the number of parallel streams in the ith stage ($g_i \geqslant 1$). The total number G of processes that are monitored by the SPC system is then equal to

$$G = \sum_{i=1}^{s} g_i. \tag{1}$$

The g_i parallel streams in the ith stage are assumed to have the same mean, standard deviation and target value (Runger et al., 1996), and each of the g_i streams will be monitored by a separate but identical control charts (with the same sample size, sampling interval and control limits). This scenario helps to detect and diagnose the out-of-control stream (Montgomery, 2001). Consequently, there are only s different charts in the M-SPC system.