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Extending a double sampling control chart for non-conforming proportion in high quality processes to the case of small samples

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ABSTRACT

When production processes reach high quality standards they are known as high quality processes. In this situation, the conventional p charts (based on 3-sigma limits) used for monitoring non-conforming products have serious drawbacks in detecting changes in p due to excess of false alarm risk. In a previous paper, the authors showed a new p chart that provides a large improvement over the usual p chart in these situations. In this paper, authors propose a new corrected version of a double sampling (DS) control chart for monitoring the proportion p of non-conforming presented in the literature for large samples, in order to extend its applicability to the case of small samples. This procedure offers better statistical efficiency (in terms of the average run length) than the previous p charts, without increasing the sampling. Tables are provided to aid in the choice of DS parameters. The benefits of the corrected version of a DS chart for monitoring high-quality processes are illustrated with real data.

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1. Introduction

Regardless of how well designed or maintained, any manufacturing process produces inherent or natural variability as a cumulative effect of unavoidable causes. A control chart is one among other recognized statistical process control tools that, in general, is proactive and mainly aimed at monitoring the process [10]. A control chart is designed to accurately identify natural variability in a manufacturing process as a result of unassignable (or chance) causes, or non-natural variability as a result of assignable (or special) causes, which characterizes an out-of-control process.

In these cases, the traditional Shewhart control p chart has been widely used mainly because it is simple and effective but it is not sensitive in detecting small shifts that are common in today's precise manufacturing processes. This difficulty increases the risk of deciding that the process is under control when it really is out of control (beta risk of non-detection) or that the process is out of control when it really is under control (alfa risk of false alarm).

Traditionally, the conventional Shewhart control p charts were constructed based on the normal approximation for the binomial sampling statistic. But these charts are far from adequate for the situation of low defect level and/or when the sample size is not large enough, mainly due to skewness in the exact distribution. For small p values, the binomial distribution is highly asymmetric, and as a result, any attempt to monitor p with symmetric control limits, is subject to excess of false alarm.

A number of alternatives have been proposed to improve the power and sensitivity of control p charts in high quality process. A good survey can be found in [16]. But, although these proposed charts can increase the monitoring accuracy, they still lack the desirable accuracy when the true p is very small and n is not large.

In a previous paper [9], the authors presented an improved p chart which can provide a considerable improvement over the usual p chart for attributes. This new chart, based on the Cornish–Fisher expansion for quantile correction is also better than the traditional Shewhart control chart especially in the sense that it allows monitoring lower values of p as is the case in high-quality processes. The proposed method consists in making an adjustment on the control limits that depends only on the sample size and the value of the process parameters.

This improved control chart can detect large increases in the nonconforming rate p but is not efficient for detecting small increments of the process parameters. For these situations, an alternative to control charts for attributes with simple sampling is the application of control charts with double sampling (DS). Double sampling is a special case of multiple sampling consisting in taking decisions in two steps instead of in a single step as is usual in control charts.

The DS control chart was firstly proposed by Croasdale [5] in control charts for variables. In this first DS control chart, information from the first and second samples is evaluated separately, and confirmation is done only with the second sample. Daudin [6] improved Croasdale's DS control chart, and proposed a DS control chart that uses the information from both samples at the second stage. The larger sample size improves the precision of the control chart since it uses a smaller sample standard deviation. In estimating the control chart limits, Daudin's DS control chart is optimized with respect to the expected sample size. Instead of minimizing the expected sample size, [8] maximized the power of the control chart to determine the control chart limits. He et al. [7] and Costa and Claro [4] have made further development of DS control chart for variables.

More recently, research has been conducted to improve the effectiveness of the np charts. Wu et al. [14] developed an algorithm for the optimization design of the np control chart with curtailment, considering 100% inspection. Wu and Wang [15] proposed an np chart with a double inspection feature. The first inspection decides the process state (in control or out of control) according to the number of non-conforming items found in a sample and in the second inspection, the proposed chart checks the location of a particular non-conforming item in a sample.

Rodrigues et al. [12] proposed a two-stage sampling or double-sampling (DS) combined with Shewhart control charts. This is another method used to improve the performance of traditional Shewhart control p charts, without increasing the (in-control) average number of items inspected per time unit. During the first stage, one or more items from the sample are inspected and, depending on the results, the sampling is interrupted or it goes on to the second stage, where the remaining sample items are inspected.