

Control Charts for Short Production Runs in Aerospace Manufacturing

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ABSTRACT

Statistical process control (SPC) has been extensively used in many different industries including automotive, electronics, and aerospace, among others. SPC tools such as control charts, process capability analysis, sampling inspection, etc., have definitive and powerful impact on quality control and improvement for mass production and similar production systems. In aerospace manufacturing, however, applications of SPC tools are more challenging, especially when these tools are implemented in processes producing products of large sizes with slower production rates. For instance, following a widely accepted rule-of-thumb, about 100 units of products are required in the first phase of implementing a Shewhart type control chart. Once established, it then can be used for process control in the second phase for actual production process monitoring and control. In many aerospace production processes, however, it requires that quality control measures be in place from the time that the first unit of product is produced. Certain types of control charts for self-starting (without the first phase) and for short production runs (as few as 3 units) have been developed by researchers and practitioners. They have been tested and used in places where traditional Shewhart control charts are difficult to apply. In this work, we used Monte-Carlo simulation to study the suitability of applying $\bar{Q}$ -chart, one of the available self-starting control charts, in comparison with $I/\overline{MR}-\bar{X}$ chart for short production runs. The preliminary results suggest that a combination of Cusum $\bar{Q}$ -chart and Cusum $I/\overline{MR}-\bar{X}$ chart be considered for better quality monitoring and control.

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INTRODUCTION

Statistical process control and Shewhart control charts have been extensively used with great successes in many different industries in the past many decades [1]. In general, a two-phase approach is required to implement a Shewhart control chart. In the first phase of using $\bar{\bar{x}} - R$ control charts, for example, for monitoring variable quality characteristics, multiple samples of products with several units in each sample are taken to estimate the process centering μ and process standard deviation σ . In practice, the "rule-of-thumb" is to use about 100 units of products in this first phase [1]. More specifically, 20 samples with 5 units in each sample (sample size of 5) or 25 samples with 4 units in each sample (sample size of 4) are commonly used to estimate the process parameters μ and σ . In addition, these 100 or so units should be taken randomly according with rational subgroup considerations [1] from a much larger pool of products. If the control charts constructed in this first phase (with revisions, if

necessary) show that the production process was in statistical control during the time that the samples were taken, it can proceed to the second phase of implementation. In the second or the production phase, the control chart established with the process mean and process variance estimated in the first phase. In implementing an $\bar{\bar{X}}$ control chart, for example, its center line will be set at the average value of the sample means and its upper and lower control limits will be calculated also using the information collected in the first phase. This is the typical two phase approach when the process centering and variance are unknown and the estimates of these parameters are generated in the first phase. On the other hand, if the process centering and variance are known in advance, it normally still requires the first phase to validate that the process is in control and performs in line with the known parameters. In mass production or in a system producing large number of different products with however similar controlled characteristics such as material,

part features, etc., the 100 or so units required in the first phase can be obtained without serious negative impact on the long term production. However, in a manufacturing system producing products of very expensive parts or products with slower production rates, the requirement of having 100 units can cause serious problems in implementing SPC charts or in using other statistical quality control tools. In many such cases, it would be unrealistic to have such number of products for the purpose of evaluating the performance of a production process. In aerospace manufacturing, for example, production rates of producing large parts such as aircraft cockpits, fuselages or wings, can be much slower than those in mass production. In addition, such parts are much more expensive to produce with high level of quality requirement. It will be impractical and impossible to have about 100 units of such large products as samples to construct a control chart to be used in the following production phase. In addition to all quality related design and certification requirements for such product or component manufacturing, it is highly desirable that the manufacturing process is closely monitored as early as possible. It will also be desirable if the quality control and monitoring mechanism in the early stage of production is consistent with that to be used in the entire production cycle. Specifically, the following and possibly other challenges related to using SPC tools in aerospace manufacturing need to be addressed:

- SPC charts and other statistical methods are powerful tools for monitoring and ensuring consistent production of high quality products. They should be used wherever possible.
- Statistical information from 100 or more products from the same process is the acceptable size of data to establish traditional SPC charts based on the practices in the past many decades.
- In aerospace and other similar manufacturing systems producing large and expensive products with slower production rates, quality of the products and performance of the processes must be evaluated as early as possible. It is highly desirable that the performance of such process is at the highest quality level when the first unit is produced and remains so in producing every other unit of the product.
- The two-phase approach used in implementing traditional SPC charts or other tools may not be applicable in aerospace manufacturing systems or similar manufacturing systems.
- “Self-starting” control charts and tools (without requiring the first phase for implementing traditional SPC charts) should be used to effectively monitor such systems at their early stage of production.
- The SPC control charts or tools to be used in monitoring such systems at its early stage of production should have certain continuity with those used in the later stage when sufficient statistical data become available.

As can be seen from the literature, problems and challenges related to developing and implementing self-

starting control charts for monitoring short run or “batch” production have been studied by many researchers and practitioners. Different methods have been developed and proposed to address some of the above mentioned aspects of these challenges to certain extent under specific application conditions. Various control charts for short production runs and for self-starting processes have been proposed for different production systems. The Shewhart control charts based on $\bar{Q}$ statistics proposed by Quesenberry [2] have attracted much attention from many researchers and practitioners. Zantek [3] noted that a similar procedure was proposed earlier in Hawkins [4]. Application of $\bar{Q}$ chart is reported in [5]. Further studies on $\bar{Q}$ chart are shown in many research papers ([6] and [7], for example). Al-Salti and Statham [8] reviewed research papers published in or before 1993 on using SPC tools, including $\bar{Q}$ charts, for short production runs or batch production systems. More recently, control chart based on t statistic was proposed in [9] for short production runs. It was followed by the work on EWMA t charts in [10] and that on Cusum t charts in [11] with further studies. The t chart is similar to $\bar{Q}$ chart in that both of them use t statistics. In this research, we studied the performance of individual $\bar{Q}$ chart using $\bar{Q}$ statistics in I/MR plotting for very short production runs. The purpose is to investigate the applicability of such charts for monitoring processes with slow production rates. The I/MR- $\bar{Q}$ chart was compared with several other charts including Cusum $\bar{Q}$ chart in addressing the signal fading issue associated with $\bar{Q}$ charts. The study of $\bar{Q}$ chart performance and the comparison with other charts were conducted through Monte-Carlo simulation.

Q AND X-BAR STATISTICS WITH I/MR AND CUSUM CHARTS

In this section, the $\bar{Q}$ statistics proposed in [2] with brief explanations on its suitability for short run production systems such as processes producing large size products in aerospace manufacturing.

The $\bar{Q}$ Statistics

The $\bar{Q}$ statistics considered in this study are based on unknown process mean and process variance [2] at the time that the self-starting control chart is to be used. Let $X_1, X_2, X_3, X_4, \dots$ be the values of the quality characteristic of individual parts 1, 2, 3, 4, ..., respectively. The steps to generate the $\bar{Q}$ statistics based on these individual readings are shown below [2]:

$$\bar{X}_i = \frac{1}{i} \sum_{k=1}^i X_k, i = 1, 2, 3, 4, 5, \dots \quad (1)$$

$$\hat{\sigma}_i^2 = \frac{1}{i-1} \sum_{k=1}^i (X_k - \bar{X}_i)^2,$$

$$a_i = \sqrt{(i-1)/i}, \quad i = 2, 3, 4, 5, \dots$$

(2)

$$T_i = a_i (X_i - \bar{X}_{i-1}) / \hat{\sigma}_{i-1}, \quad i = 3, 4, 5, \dots$$

(3)

Let $G_i(\cdot)$, $i = 1, 2, 3, 4, 5, \dots$ be the cumulative distribution function of Student t distribution with i degrees of freedom. Then the Q statistics is calculated by:

$$Q_i = \Phi^{-1}(G_{i-2}(T_i)), \quad i = 3, 4, 5, \dots$$

(4)

where in Eq (4), $\Phi^{-1}(\cdot)$ is the inverse of standard normal cumulative distribution function.

If the variable X representing the concerned quality characteristic is the result from assembling several components or subassemblies, it can reasonably be expected that X follow a normal distribution. The principle of using Q chart is that, if $X_1, X_2, X_3, X_4, \dots$ are normally distributed independent variables with common mean μ and variance σ^2 (in other words, the process is in statistical control), the Q_i , $i = 3, 4, 5, \dots$ values should be plotted within the control limits of a standardized 3σ control chart. The standardized 3σ control chart is centered at 0 with lower control limit at -3 and upper control limit at +3. It has the simplest form of a control chart.

Advantages of Q Charts

The idea of using Q statistics to establish a self-starting monitoring process is quite straightforward. It calculates the Student t statistics iteratively based on any given number of observations. In essence, the process mean can be estimated with the measurement of the quality characteristic of the first unit of the product. When the second unit is available, the process mean can be better estimated with the 2 measurements and the first estimate of the process variance can be calculated. These are achieved using Eqs. (1) and (2) in the previous sub-section. The t statistics, or T_i in Eq.(3), can be generated when the measurements of 3 units become available. It can be placed in a control chart using the estimated parameters based on the first 2 measurements. The Student t statistics provide information on the consistency of the process as established in classical statistics. In the considered circumstance, if the first t value T_1 is plotted outside the control limit of such a control chart, it may indicate that the process has changed when the 3rd unit is produced comparing to that when the first 2 units were made. In practice, if the T_i values are used directly without being converted to the Q statistics using the inverse function of standard normal distribution as shown in Eq.(4) (or using other similar conversions), the centerline and control limits of the control chart need to be updated every time a new

measurement data is incorporated. This would be impractical in a shop-floor application. Transforming the t statistics to Q statistics using Eq.(4) will allow the Q values to be plotted in a standardized control chart centered at 0 with lower control limit at -3 and upper control limit at +3.

The main reasons that we consider the Q charts for possible applications in aerospace manufacturing systems are:

- It is a self-starting control chart and does not require the trial phase or the first phase in implementing a Shewhart type control chart.
- It is particularly useful in that one can start plotting the Q statistics as soon as the system produces 3 units of products. It is based on sound statistics.
- It is simple to calculate the Q statistics. The required Student t distribution and normal distribution functions are readily available in MS-Excel or any other basic statistics software.
- It is easy to implement. It is a standardized control chart with the center line at 0 and control limits at ± 3 . No other calculations or data conversion are need. The use of such chart is less burdensome for shop floor operators.
- When more units are produced, statistical data and information from the implemented Q charts can be used to establish other traditional control charts with larger data set becoming available.

The considerations presented above make the Q chart a good candidate chart for short run production systems.

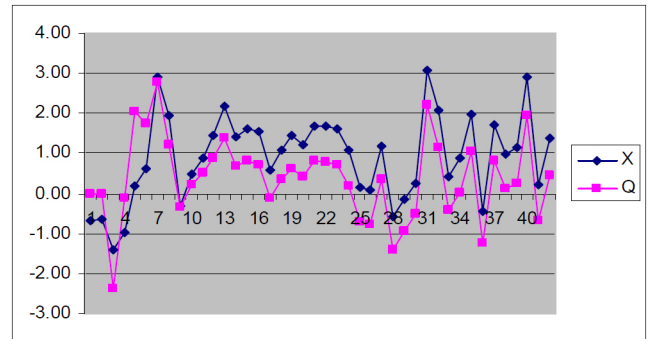


Figure 1. Comparing Individual Q and X plotting

As pointed out by many researchers, the Q chart is also associated with certain limitations. One of the major concerns is that the signal of a shift may be less visible from the Q chart plotting if it is not detected promptly. For example, if a sustained shift of the centering occurs but is not detected immediately by the Q chart, it is more unlikely to be detected later since the Q statistics transform the T_i values into those following a standard normal distribution. Figure 1 shows one of the experimental plots in comparing individual X and Q statistics. The first 6 plots of the X plots comes from a standard normal distribution and the remaining of them come