Determination of sample size of control chart based on APQ

Huizhen Zhao*, Lili Meng, Caihua Wang and Xiaowei Sun
School of Mechanical Engineering, North China University of science and technology, Tangshan, China

*Corresponding author: huizhenzhao@ncst.edu.cn

Abstract. The SPC control chart is an important quality tool to determine whether there are abnormalities in the production process. When making control charts, the sample size is generally selected based on experience, which has certain limitations. To determine the sample size more accurately, the average run length (ARL) is used to measure the quality characteristics of the control chart, and the relationship between the average run length and the two types of errors is analysed to establish an APQ-based sample size related mathematical model. The model is analysed using Minitab software and Excel to finally determine the appropriate sample size scale for different cases.

Keywords: average production yield (APQ), SPC control chart, average run length (ARL), sample size.

1. Introduction
When using control charts for quality testing, the traditional method generally selects a control limit factor of 3, a sample group size of 20 or 25, and a sample size of 4 or 5. This method has been widely used in quality testing. However, the principle of sample size and sampling interval selection is to minimize the fluctuation of non-systematic factors within the group, so that the fluctuation between groups is as large as possible, in order to detect abnormalities in a timely manner. Therefore, it is not appropriate to use fixed control limit parameters. Appropriate sample size, sampling interval and control limit coefficients should be used according to the specific actual situation.

2. APQ mathematical model
The concept of out-of-control APQ is the average yield of the product during the period from the time when an abnormality occurs in the production process to the time when the abnormality is detected by the system, while the concept of controlled APQ is the average yield of the product during the period from the time when the production process is detected to the time when the abnormality occurs in the production process but is not detected, which can be simply expressed as the value of APQ. The value of APQ can be used as an important indicator to measure the quality characteristics of the control chart. Firstly, the lower limit value of APQ is determined, and on this basis, a scientific and reasonable method is used to select the appropriate sample size n, sampling frequency t and control limit width parameter k to minimize the value of uncontrolled APQ as much as possible, so that the quality control capability of SPC control chart can be optimized to a certain extent.

It is assumed that the quality tests are independent of each other and essentially conform to a normal distribution with standard deviation σ. The model holds on the premise that if an abnormality occurs in
a sample, the abnormality is ignored in this sample and the resulting abnormality may be found only in the next sample. In addition, assuming that the production capacity of the machine is $N$, the sampling interval is $t$, and the capacity of each sample is $n$, the sampling proportion is \( r = \frac{n}{tN} \), and the mean shift is expressed as \( d = \frac{|\mu_1 - \mu_0|}{\sigma} \) ($\mu_0, \sigma$ known).

APQ can be expressed as follows.

\[
APQ = \frac{n}{r} \times \frac{1}{1 - \Phi(-d \sqrt{N} + kD) + \Phi(-d \sqrt{N} - kD)} - \frac{n}{2r} \tag{1}
\]

Where $\Phi(x)$ is the standard normal distribution function, $k$ is the width factor of the control limits, $n$ is the sample size, and $r$ is the sampling proportion, such that the mean offset is $d = \frac{|\mu_1 - \mu_0|}{\sigma}$, and the standard deviation offset is $D = \frac{\sigma_0}{\sigma_i}$. The representation symbols of these parameters are applied to the full text.

3. APQ-based sample size model

On the basis of equation (1), with no shift in the mean and standard deviation, we can obtain $d=0, D=1$, at which time the APQ is $APQ_0$ affected by $\alpha$ and $N$. In addition, it can be known that $1 - \Phi(k) = \emptyset(-k)$, then equation (1) can be expressed as

\[
APQ_0 = \frac{n}{r} \times \frac{1}{1 - \Phi(k) + \Phi(-k)} = \frac{n}{2r} = \frac{n}{2r} \times \frac{1}{1 - \Phi(k)} = \frac{n}{2r} \tag{2}
\]

According to equation (2) we can obtain.

\[
\Phi(k) = \frac{2rAPQ_0}{2rAPQ_0 + n} \tag{3}
\]

Then $k$ can be expressed as

\[
k = \Phi^{-1} \left( \frac{2rAPQ_0}{2rAPQ_0 + n} \right) \tag{4}
\]

Since $k$ is the width coefficient of the control limit, it follows that we have $k \geq 0$; according to the nature of the standard normal distribution, we have $\Phi(k) \geq 0.5$, then equation (3) can be expressed as

\[
\frac{2rAPQ_0}{2rAPQ_0 + n} \geq 0.5 \tag{5}
\]

Simplifying equation (4), we have.

\[
n \leq 2rAPQ_0 \tag{6}
\]

Now, a complete mathematical model can be built.

\[
Min APQ = \frac{n}{r} \times \frac{1}{1 - \Phi(-d \sqrt{N} + kD) + \Phi(-d \sqrt{N} - kD)} - \frac{n}{2r} \tag{7}
\]

Meet: $n = 1, 2, 3, \ldots \text{int}(2rAPQ_0)$

Where $k = \Phi^{-1} \left( \frac{2rAPQ_0}{2rAPQ_0 + n} \right)$, $r$ and $d$ are fixed values.

Using the method of single-objective planning in operations research, equation (7) is solved to derive the sample size $n$. 
4. Analysis of APQ model results

The effect of different sample sizes on APQ values is analysed below. On the basis of this study, the sampling ratio \( r \) and controllable APQ \( APQ_0 \) should be given, so the more commonly used parametric data are used for the analysis and \( APQ_0 = 10000 \) and sampling ratio \( r = 0.01 \) are chosen.

4.1. Analysis of APQ results when both the mean and standard deviation are skewed

This situation is most common in practical production, and if both the mean and variance are deviated, \( d \neq 0 \) and \( D \neq 1 \). The effect of sample size on APQ with different standard deviations is plotted with Minitab for sample sizes between 1 and 25, when the mean deviation \( d = \frac{|\mu_1 - \mu_0|}{\sigma} = 1 \), as shown in Figure 1.

![Figure 1. Relationship between sample volume and APQ at different standard deviation biases](image)

The plot is significantly different from the plot at mean offset \( d = 0 \), which shows that the mean offset and standard deviation offset produce mutual constraints that make the sample capacity have different effects on APQ. From the above figure, it can be seen that the APQ value increases gradually with the increase of sample size when the standard deviation \( d = 0.5 \), and reaches the minimum value when the sample size is 1. The rest of the APQ values show a phenomenon of decreasing and then increasing at different standard deviation offsets, so the corresponding minimum values can be obtained at different sample size points. In addition, it can be seen from the figure that the larger the standard deviation offset, the larger the corresponding APQ value, and as the standard deviation offset increases, the sample volume corresponding to the minimum APQ value also increases. Therefore, minimizing the standard deviation offset can reduce the quality control cost and the invalid cost of producing non-conforming products to a great extent when the production conditions allow.

In the following, we choose the standard deviation bias \( D = \frac{\sigma_0}{\sigma_1} = 0.85 \), and use Minitab to make a plot to observe the effect of sample size on APQ with different mean bias, as shown in Figure 2.
Figure 2. Relationship between sample size and APQ at different mean shifts

From the graph, it can be seen that at $d=2.5$, the value of APQ gradually increases with the increase of the sample size, and roughly conforms to the primary function curve; At other mean shifts, the value of APQ decreases and then increases with the increase of sample volume, so the minimum value of APQ can be obtained at different sample volume points, and the sample volume corresponding to the minimum APQ value becomes smaller and smaller with the increase of the mean shift. Therefore, a suitable mean deviation should be selected in product production.

4.2. Determining the sample size

(1) In the production scale and production batch is relatively small, the sampling ratio $r=0.2$ is selected, and some of the best sample sizes are shown in Table 1.

| $r=0.2$ | 5000 | 10000 |
|---------|------|-------|
| $APQ_0$ | 0.5  | 1.0   | 1.5  | 2.0  | 2.5  | 0.5  | 1.0   | 1.5  | 2.0  | 2.5  |
| D \ d   | 0.5  | 13    | 3    | 2    | 1    | 1    | 17   | 4    | 2    | 1    |
|         | 0.7  | 13    | 5    | 3    | 2    | 1    | 29   | 10   | 5    | 4    |
|         | 0.85 | 17    | 7    | 3    | 2    | 2    | 34   | 11   | 5    | 4    |
|         | 0.9  | 19    | 7    | 4    | 2    | 2    | 36   | 12   | 6    | 4    |
|         | 1.0  | 22    | 8    | 4    | 3    | 2    | 38   | 14   | 7    | 4    |

Table 1. Partial capacity table for sampling ratio $r = 0.2$

(2) In the production scale and production lot is relatively large, the sampling ratio $r=0.05$ is selected, and some of the best sample sizes are shown in Table 2.

| $r=0.05$ | 20000 | 50000 |
|----------|-------|-------|
| $APQ_0$  | 0.5   | 1.0   | 1.5  | 2.0  | 2.5  | 0.5  | 1.0   | 1.5  | 2.0  | 2.5  |
| D \ d    | 0.5   | 18    | 5    | 3    | 2    | 1    | 20   | 5    | 3    | 2    |
|          | 0.7   | 33    | 11   | 6    | 3    | 2    | 40   | 11   | 7    | 4    |
|          | 0.85  | 40    | 13   | 6    | 4    | 2    | 48   | 12   | 8    | 4    |
|          | 0.9   | 42    | 13   | 7    | 4    | 3    | 50   | 16   | 8    | 5    |
|          | 1.0   | 44    | 14   | 7    | 4    | 3    | 52   | 17   | 8    | 5    |

(2) In the production scale and production lot is relatively large, the sampling ratio $r=0.05$ is selected, and some of the best sample sizes are shown in Table 2.
Table 2. Partial capacity table for sampling ratio $r = 0.005$

| $APQ_0$ | 5000 | 10000 |
|---------|------|-------|
| $D \setminus d$ | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 |
| 0.50 | 4 | 2 | 1 | 1 | | 6 | 2 | 1 | | |
| 0.70 | 7 | 3 | 2 | 1 | 1 | 9 | 5 | 3 | 2 | 1 |
| 0.85 | 9 | 4 | 3 | 2 | 1 | 11 | 5 | 3 | 2 | 2 |
| 0.90 | 10 | 5 | 3 | 2 | 1 | 12 | 6 | 3 | 2 | 2 |
| 1.00 | 12 | 5 | 3 | 2 | 2 | 13 | 6 | 3 | 2 | 2 |

| $APQ_0$ | 20000 | 50000 |
|---------|------|-------|
| $D \setminus d$ | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 |
| 0.50 | 9 | 3 | 1 | 1 | 1 | 11 | 3 | 2 | 2 | 1 |
| 0.70 | 12 | 5 | 3 | 2 | 2 | 16 | 8 | 5 | 3 | 2 |
| 0.85 | 16 | 7 | 4 | 3 | 2 | 23 | 9 | 5 | 3 | 2 |
| 0.90 | 17 | 7 | 4 | 3 | 2 | 24 | 9 | 5 | 3 | 2 |
| 1.00 | 18 | 7 | 4 | 3 | 2 | 25 | 9 | 5 | 3 | 2 |

(3) In the production scale and production lot of moderate, the sampling ratio $r=0.1$ is selected, and some of the best sample sizes are shown in Table 3.

Table 3. Partial capacity table for sampling ratio $r=0.1$

| $APQ_0$ | 5000 | 10000 |
|---------|------|-------|
| $D \setminus d$ | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 |
| 0.50 | 10 | 3 | 2 | 1 | 1 | 13 | 4 | 3 | 2 | 1 |
| 0.70 | 19 | 5 | 4 | 2 | 1 | 23 | 9 | 4 | 4 | 2 |
| 0.85 | 15 | 8 | 4 | 2 | 2 | 29 | 12 | 5 | 4 | 2 |
| 0.90 | 29 | 9 | 4 | 3 | 2 | 35 | 14 | 6 | 4 | 3 |
| 1.00 | 34 | 11 | 5 | 4 | 2 | 39 | 17 | 6 | 5 | 3 |

| $APQ_0$ | 20000 | 50000 |
|---------|------|-------|
| $D \setminus d$ | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 |
| 0.50 | 18 | 6 | 4 | 3 | 1 | 21 | 9 | 5 | 4 | 2 |
| 0.70 | 26 | 11 | 6 | 4 | 2 | 30 | 13 | 7 | 5 | 3 |
| 0.85 | 30 | 15 | 8 | 5 | 3 | 35 | 16 | 8 | 5 | 3 |
| 0.90 | 39 | 15 | 8 | 5 | 3 | 43 | 18 | 8 | 5 | 3 |
| 1.00 | 42 | 19 | 8 | 6 | 4 | 47 | 23 | 10 | 6 | 4 |

(4) In the production scale and production lot of moderate, the sampling ratio $r=0.01$ is selected, and some of the best sample sizes are shown in Table 4.

Table 4. Partial capacity table for sampling ratio $r=0.01$

| $APQ_0$ | 5000 | 10000 |
|---------|------|-------|
| $D \setminus d$ | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 |
| 0.50 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0.70 | 1 | 3 | 2 | 1 | 1 | 1 | 4 | 2 | 1 | 1 |
| 0.85 | 10 | 4 | 3 | 2 | 1 | 14 | 5 | 3 | 2 | 1 |
| 0.90 | 11 | 5 | 3 | 2 | 1 | 15 | 6 | 3 | 2 | 2 |
| 1.00 | 13 | 6 | 3 | 2 | 2 | 19 | 7 | 4 | 2 | 2 |

| $APQ_0$ | 20000 | 50000 |
|---------|------|-------|
| $D \setminus d$ | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 |
| 0.50 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0.70 | 1 | 5 | 3 | 2 | 1 | 11 | 5 | 3 | 2 | 1 |
| 0.85 | 18 | 7 | 4 | 3 | 2 | 24 | 8 | 4 | 3 | 2 |
| 0.90 | 20 | 7 | 4 | 3 | 2 | 37 | 9 | 5 | 4 | 2 |
| 1.00 | 23 | 9 | 5 | 3 | 2 | 44 | 11 | 6 | 5 | 3 |
Note:
  a) According to the actual size of the enterprise and the production batch, the choice of different sampling ratio: large batches of $r = 0.005$; medium batch optional $r = 0.01$ and $r = 0.1$; small batches of $r = 0.2$.
  b) According to the product quality inspection level requirements, choose APQ: in the III level, choose $APQ_0 = 5000$; in the II level, choose $APQ_0 = 10000$ and $APQ_0 = 20000$; in the I level, choose $APQ_0 = 50000$.
  c) According to the range of enterprise historical mean offset $d$ and standard deviation offset $D$, choose the appropriate $d$ and $D$, so as to determine the sample capacity.

5. Case Study
A medium-sized factory produces camshafts of length $600\text{mm} \pm 2\text{mm}$ and the type of production of this camshaft is medium batch production. The quality inspection of this camshaft is carried out at the level of II normal level, and the stability of the production process is evaluated using the following two methods.

5.1. Control chart analysis under the traditional method
In the traditional method, the $3\sigma$ principle is generally used and the sample size of 3, 4 or 5 is selected. In this paper, the sample size of 5 is selected for analysis and Table 5 shows 20 sets of data for camshaft length.

| groups | x1   | x2   | x3   | x4   | x5   | $\bar{X}$ | $R$  | $S$   |
|--------|------|------|------|------|------|----------|------|-------|
| 1      | 601.4| 599.4| 598.0| 601.4| 601.6| 600.36   | 3.6  | 1.59625 |
| 2      | 600.0| 600.2| 601.2| 598.4| 599.0| 599.76   | 2.8  | 1.08995 |
| 3      | 600.6| 600.0| 599.8| 597.6| 600.2| 599.64   | 3.0  | 1.17813 |
| 4      | 599.4| 601.2| 598.4| 599.2| 598.8| 599.40   | 2.8  | 1.07703 |
| 5      | 601.6| 601.7| 601.5| 601.6| 598.0| 600.88   | 3.7  | 1.61152 |
| 6      | 601.4| 598.8| 601.6| 598.4| 601.6| 600.36   | 3.2  | 1.61493 |
| 7      | 598.2| 601.2| 599.6| 601.2| 598.8| 599.80   | 3.0  | 1.37113 |
| 8      | 597.0| 597.8| 598.2| 597.2| 601.5| 598.34   | 4.5  | 1.82975 |
| 9      | 601.2| 600.0| 597.2| 599.4| 598.8| 599.32   | 4.0  | 1.48054 |
| 10     | 601.6| 601.0| 600.2| 599.0| 601.2| 600.60   | 2.6  | 1.02956 |
| 11     | 600.8| 597.8| 599.2| 599.2| 600.6| 599.52   | 3.0  | 1.22147 |
| 12     | 598.0| 598.0| 598.8| 600.8| 601.0| 599.32   | 3.0  | 1.48054 |
| 13     | 598.2| 601.8| 601.0| 601.4| 601.4| 600.76   | 3.6  | 1.45877 |
| 14     | 599.0| 600.4| 598.4| 601.2| 602.0| 600.20   | 3.6  | 1.49666 |
| 15     | 600.8| 600.0| 600.2| 600.4| 601.4| 600.56   | 1.4  | 0.55498 |
| 16     | 599.8| 599.6| 598.0| 594.9| 599.6| 599.28   | 1.8  | 0.72938 |
| 17     | 601.2| 601.2| 600.2| 600.0| 601.0| 600.72   | 1.2  | 0.57619 |
| 18     | 600.4| 598.8| 598.8| 598.8| 600.4| 599.44   | 1.6  | 0.87636 |
| 19     | 598.8| 599.4| 599.6| 598.8| 601.0| 599.52   | 2.2  | 0.90111 |
| 20     | 599.0| 600.4| 600.2| 600.6| 601.8| 600.40   | 2.8  | 1.00000 |

The X-S control chart was used for comprehensive analysis, and the two control charts were drawn by analysing the data using Minitab software, as shown in Figure 3.
Figure 3. X bar-S control chart under the traditional method

According to the control chart above we can see that the production process in general is operating normally and in the quality process control stage, although the mean value of sample 8 is close to the lower limit value of the mean, but not out of bounds, so the system does not detect that there are abnormalities generated. Therefore, under the traditional way of inspection, the production process is considered normal and can be left unadjusted.

5.2. Control chart analysis in the optimal way

According to the type of production of the factory is medium batch production, and the batch size is relatively large, so the sampling ratio \( r = 0.01 \) is selected, so the sample size is determined by referring to Table 4; according to the quality inspection level of the factory is II normal level, so the controlled average product yield is used \( \text{APQ} = 10000 \); according to the analysis of the previous inspection results of the factory, referring to the control chart obtained in the traditional way. We get that the mean offset \( d = \frac{\mu - \mu_0}{\sigma} \) basically fluctuates around 1.0, so we choose the mean offset \( d = 1.0 \); and the standard deviation offset \( D = \frac{\sigma_0}{\sigma_1} \) is also basically around 0.7, so we choose the standard deviation offset \( D = 0.7 \). According to the values of the four parameters determined above, we can check the table and get the sample capacity of 4. According to the formula \( k = q^{-1} \left( \frac{2r\text{APQ}_0}{2r\text{APQ}_0 + n} \right) \), we get the control limit width coefficient \( k = 2.88 \), so we get the following data for the camshaft length as in Table 5, and the X-S control chart is plotted using Minitab as in Figure 4.
### Table 6. Length data of the camshaft

| groups | x1       | x2       | x3       | x4       | $\bar{x}$ | R | S     |
|--------|----------|----------|----------|----------|-----------|---|-------|
| 1      | 601.4    | 599.4    | 598.0    | 601.4    | 600.05    | 3.4| 1.66032 |
| 2      | 600.0    | 600.2    | 601.2    | 598.4    | 599.95    | 2.8| 1.15902 |
| 3      | 600.6    | 600.0    | 599.8    | 597.6    | 599.50    | 3.0| 1.31149 |
| 4      | 599.4    | 601.2    | 598.4    | 599.2    | 599.55    | 2.8| 1.18181 |
| 5      | 601.6    | 601.7    | 601.5    | 601.6    | 601.60    | 0.2| 0.08165 |
| 6      | 601.4    | 598.8    | 601.6    | 598.4    | 600.05    | 3.2| 1.68424 |
| 7      | 598.2    | 601.2    | 599.6    | 601.2    | 600.05    | 3.0| 1.44568 |
| 8      | 597.0    | 597.8    | 598.2    | 597.2    | 597.55    | 1.2| 0.55076 |
| 9      | 601.2    | 600.0    | 597.2    | 599.4    | 599.45    | 4.0| 1.67631 |
| 10     | 601.6    | 601.0    | 600.2    | 599.0    | 600.45    | 2.6| 1.12398 |
| 11     | 600.8    | 597.8    | 599.2    | 599.2    | 599.25    | 3.0| 1.22610 |
| 12     | 598.0    | 598.0    | 598.8    | 600.8    | 598.90    | 2.8| 1.32162 |
| 13     | 598.2    | 601.8    | 601.0    | 601.4    | 600.60    | 3.6| 1.63299 |
| 14     | 599.0    | 600.4    | 598.4    | 601.2    | 599.75    | 2.8| 1.27932 |
| 15     | 600.8    | 600.0    | 600.2    | 600.4    | 600.35    | 0.8| 0.34157 |
| 16     | 599.8    | 599.6    | 598.0    | 599.4    | 599.20    | 1.8| 0.81650 |
| 17     | 601.2    | 601.2    | 600.2    | 600.0    | 600.65    | 1.2| 0.64031 |
| 18     | 600.4    | 598.8    | 598.8    | 598.8    | 599.20    | 1.6| 0.80000 |
| 19     | 598.8    | 599.4    | 599.6    | 598.8    | 599.15    | 0.8| 0.41231 |
| 20     | 599.0    | 600.4    | 600.2    | 600.6    | 600.05    | 1.6| 0.71880 |

**Figure 4.** X bar-S control chart under the sample capacity table method

According to the two control charts under the optimal way, it is obvious that at sample 5 and sample 8, the mean value of the sample has been generated with obvious abnormality, at which time it can be considered that the production process has been abnormal and is out of control, and the control chart can detect this abnormality and will issue an abnormal signal to remind the staff to fix the process in time. And from the extreme difference and standard deviation control chart can be seen, the extreme
difference and standard deviation of sample 5 are very small, close to 0, which indicates that the group of data is relatively concentrated, and at the same time combined with the mean value control chart, sample 5 is out of bounds, so the reason for the abnormality of sample 5 can very well be the main reason for the abnormality of the whole process, and should be made in time to respond to measures.

5.3. Comparison of the two methods
As can be seen from the case study just now, in the traditional control chart analysis, no abnormality was detected in the production process, only a trend of abnormality at sample 5; while when the optimal sample capacity was used for the analysis, two abnormal points were detected and sample 5 was detected very clearly. The control limit coefficients of these two methods are k=3 and k=2.88, and the sample capacity is 5 and 4, respectively. The difference between the values of these two parameters is not much, but there is a big difference in the performance of the control chart. When using the optimal sample size method for detection, not only is the sample size taken relatively smaller, but also the abnormalities occurring in the production process can be detected and the system signals process abnormalities, saving the cost of detection and production. The traditional control chart only uses $3\sigma$ control limits for quality monitoring, this method is not applicable to so product production, the requirements for product accuracy are different and the same rules cannot be used, while the optimal sample volume method, which takes into account a variety of variables affecting the performance of the control chart, enables the control chart to more accurately demonstrate the true production status, thus improving the sensitivity and accuracy of the control chart, timely of identifying abnormality and avoiding unnecessary losses.

6. Conclusion
The two types of errors that deviate from the control chart can affect the reflection of the control chart on the production process to different degrees. The average run length is chosen to elicit the average production yield (APQ), and the runaway APQ is used as an indicator to measure the performance of the control chart to monitor the production process. A mathematical model between the runaway APQ and the sample capacity is established to minimize the runaway APQ on the basis of a given lower limit of the controlled APQ. The effects of different sample capacities on APQ when different mean shifts and standard deviation shifts are applied are analysed, and the most suitable sample capacity table for different cases is finally derived. Through the case study, the control charts under the two methods of traditional method and sample capacity table are compared to verify the scientifically and accurately of the sample capacity table.

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