An Effectiveness Study of SPC Control Charts on the Quality Control for Construction in Asphalt Pavement

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Abstract.: Aiming at the problems of insufficient dynamic control and data mining of Expressway pavement construction quality in Yunnan, this paper analyzes the application of Exponentially Weighted Moving Average (EWMA) control chart in dynamic control of Expressway asphalt pavement construction quality. Firstly, the quality characteristic value of pavement construction is defined as the data type of multiple variation sources, and the mathematical model of multiple variation sources is studied to solve the problem of excessive false alarm. Then, on the theoretical basis of statistical process control (SPC), the paper compares and analyzes the three control chart schemes of traditional Hugh Hart control chart, Tabular Cumulative Sum (CUSUM) control chart and EWMA control chart, and concludes that the application effect of EWMA control chart is obviously better than the other methods in the aspects of applicability and inspection output. Finally, combining with the measured data of asphalt mixture temperature and asphalt weight in pavement construction, EWMA control diagram is used to carry out practical research, and the results are better. Keywords: Road engineering; Quality Dynamic Control; Exponentially Weighted Moving Average; Statistical Process Control; Multiple Sources

1. introduction

As the core of highway construction, quality problems are the key to determine the success or failure of its construction directly. Therefore, quality control is also one of the most important components in the three control-objectives of highway construction projects. The basic purpose of construction quality control is to achieve the stipulated quality standards and ensure the stability of construction quality. However, we often currently focus on achieving the standard requirements, not the stability of the quality. In the 13th Five-Year Plan (2016-2020), 82 highway projects were started to construct with the total mileage of 7186 km in Yunnan Province, China. More specifically, there were 19 national highway projects with the total mileage of 1946 km and 67 provincial highway projects with the total mileage of 5240 km. The construction of highway will be promoted rapidly to create a more comprehensive traffic network from 2021 to 2030. Therefore, the tasks of constructing highway projects are still heavy in the next decade. In the yuxi section of Yuanman highway construction process, an Information System
(Information System) as a technology platform through the engineering data collection and analysis to study the quality control of effective method are needed to conduct due to a lot of construction data, which could achieve the purpose of the construction process control.

SPC is a method that uses statistical methods and tools to analyze and monitor process variability in order to ensure process stability and improve process performance [1-2]. Control charts are an example of a tool used for SPC. Hugh Hart, CUSUM and EWMA are three widely used charts to detect changes in process parameters [3]. The use of control charts assumes that the observations from the process are independent and normally distributed. If these assumptions are violated, the graph would break down and may result in frequent false alarm signals, even if the process is stable [4].

It is one of the most commonly used mathematical means to control stability in construction quality control and management to analyze accidental and abnormal fluctuation of quality in the process of production by scientific statistical analysis theory, so as to give timely warning to abnormal fluctuation of quality in the process [5-6]. SPC based on Control charts is widely used in mathematical statistical analysis [7-8]. Among these charts, the Xbar-R control chart in the Hugh Hart control chart is the most commonly used and the most basic control chart type [9]. However, this kind of control chart lacks the ability to detect the fluctuation of the mean value, and only considers the error sources within the sample itself, and lacks the analysis of various sources of variation in the construction process. Many researches at home and abroad have shown that EWMA control chart has a more significant effect on detecting the mean deviation of quality parameters in the control and correction of a certain variation source, and is more reliable and practical [10-12].

Therefore, this paper presents a variation source mathematical model of the construction process of asphalt pavement based on the theory of statistical quality control. Then, the contrast of inspection level in CUSUM and EWMA control charts is conducted. Finally, the analysis of the temperature of asphalt and asphalt content in practical control effect is performed, which could verify the effectiveness of the EWMA control chart in engineering applications.

2. analysis of multiple-source variation
In the past, the quality control in the process of asphalt pavement construction only considered the fluctuation between batches, such as the temperature difference between different batches of asphalt mixture. But if raw material internal variation (i.e., position variation, such as measuring the temperature of the asphalt mixture, the surface and internal temperature difference) and raw material variation between each time (as batch asphalt mixture mixing the difference of the temperature at the same position) can't ignore the influence of the timing, they should be included more random factors and fixed the allergen analysis model [13].

\[ X_{ijk} = \mu + \alpha_i + \beta_{j(i)} + \varepsilon_{k(i)} \]

\[ i = 1, 2, \ldots, a \]

\[ j = 1, 2, \ldots, b \]

\[ k = 1, 2, \ldots, n \]

3. comparison of control charts
As shown in Fig. 1, the process control chart can be obtained by rotating the normal distribution graph clockwise for 90° and then turning it up and down for 180°. There are Center Line (CL), Upper Control Limit (UCL) and Lower Control Limit (LCL) on the diagram. This control method is economical and effective along with the quality supervision of the production process, but there are certain risks for the sampling and testing of samples, and there may be two common types of errors:
Cusum control chart and EWMA control chart are relatively excellent improved control charts\cite{14}, and their comparison with the traditional Shewhart control chart is shown in Table 1:

![Figure 1. Sketch map of probability for two kinds of errors](image)

**Table 1. Comparison of three control charts**

| Control Chart | Hugh Hart | CUSUM | EWMA |
|---------------|-----------|-------|------|
| Variation     | Univariate| Multivariate| Multivariate|
| Offset detection of $\mu$ | No | Yes | Yes |
| Calculation formula of control limits | $UCL = \bar{X} + A_R R$ | $UCL = \bar{X} + 3\sqrt{\sigma^2_a + \sigma^2_b + \sigma^2_{b'n}}$ | $UCL = \bar{X} + 3\sqrt{\sigma^2_a + \sigma^2_b + \sigma^2_{b'n} \left( \frac{r}{2-r} \right)}$ |
| $LCL = \bar{X} - A_R R$ | $LCL = \bar{X} - 3\sqrt{\sigma^2_a + \sigma^2_b + \sigma^2_{b'n}}$ | $LCL = \bar{X} - 3\sqrt{\sigma^2_a + \sigma^2_b + \sigma^2_{b'n} \left( \frac{r}{2-r} \right)}$ |

### 4. Project case

This paper takes the asphalt mixture temperature and asphalt weight construction indexes during the pavement construction of Yuxi section of Yuanman Expressway in Yunnan Province as an example to explain in detail the application of statistical process analysis and exponential weighted moving average control chart in the construction of Yuanman Expressway.

**Table 2. Demographic data for the temperature asphalt mixture (°C)**

| Number of batches | Mixture A | Mixture B | Mixture C |
|-------------------|-----------|-----------|-----------|
|                   | $x_1$ | $x_2$ | $x_3$ | $x_1$ | $x_2$ | $x_3$ | $x_1$ | $x_2$ | $x_3$ |
| 1                 | 177.4 | 177.7 | 176.6 | 176.8 | 177.7 | 177.5 | 177.5 | 177.2 | 176.8 |
| 2                 | 176.5 | 177.5 | 177.5 | 177.6 | 175.7 | 175.6 | 176.2 | 176.3 |
| 3                 | 178.3 | 179.2 | 178.2 | 178.1 | 178.5 | 177.2 | 178.1 | 177.2 | 178.3 |
| 4                 | 176.1 | 176.2 | 176.2 | 176.3 | 177.4 | 177.2 | 176.3 | 176.2 | 176.2 |
| 5                 | 179.2 | 178.1 | 177.2 | 178.3 | 177.8 | 177.5 | 177.2 | 176.5 | 176.6 |
| 6                 | 177.2 | 177.3 | 177.2 | 178.2 | 179.1 | 177.2 | 178.1 | 177.6 | 179.1 |
| 7                 | 178.3 | 179.2 | 178.2 | 178.1 | 178.5 | 177.2 | 178.1 | 177.2 | 178.3 |
| 8                 | 179.2 | 178.1 | 177.2 | 178.3 | 177.8 | 177.5 | 177.2 | 176.5 | 176.6 |

**Table 3. Demographic data for the weight of asphalt mixture (kg)**

| Number of batches | Mixture A | Mixture B | Mixture C |
|-------------------|-----------|-----------|-----------|
|                   | $x_1$ | $x_2$ | $x_3$ | $x_1$ | $x_2$ | $x_3$ | $x_1$ | $x_2$ | $x_3$ |
| 1                 | 78.1  | 78.1  | 78.1  | 77.9  | 77.8  | 77.9  | 79.2  | 78.3  | 79.5  |
| 2                 | 79.3  | 79.3  | 79.3  | 77.2  | 77.1  | 77.2  | 78.5  | 78.9  | 78.6  |
| 3                 | 77.7  | 77.7  | 77.9  | 77.9  | 77.9  | 77.8  | 76.9  | 77.8  | 79.1  |
| 4                 | 77.2  | 77.2  | 77.2  | 77.8  | 77.8  | 77.7  | 76.9  | 77.5  | 78.9  |
| 5                 | 77.2  | 77.2  | 77.2  | 78.2  | 78.2  | 78.2  | 78.8  | 78.8  | 78.8  |
| 6                 | 78.1  | 78.1  | 78.1  | 77.9  | 77.8  | 77.9  | 79.2  | 78.3  | 79.5  |
| 7                 | 78.3  | 78.3  | 78.2  | 78.3  | 78.3  | 78.3  | 78.3  | 77.2  | 76.6  |
| 8                 | 77.2  | 77.2  | 77.2  | 78.2  | 78.2  | 78.2  | 78.4  | 78.3  | 78.3  |

According to the data shown in the above table and combined with the theoretical analysis and calculation of multiple sources of variation in Part 1, we can get, $\sigma_a^2 = 0.0548$, $\sigma_b^2 = 0.0172$, $\sigma_c^2 = 0.0264$. 
Therefore, their proportions in the total variance were 55.69%, 17.48% and 26.83%, respectively, indicating that the influence of the three variation sources could not be ignored. For bitumen weight sample data: \( \sigma^2 = 0.0759, \sigma^2 = 0.0158, \sigma^2 = 0.00006 \), the effect of location variation on the population is negligible. The temperature of asphalt mixture and the weight of asphalt can be comprehensively obtained, which need to consider three and two sources of variation, respectively. Therefore, the traditional Shewhart control chart can no longer meet the requirements of quality control.

As can be seen from Table 1, EWMA control chart and CUSUM control chart are both applicable to the analysis of multiple sources of variation and can detect the deviation of the mean value. In the process of multi-source variation control, the detection ability and average running length of EWMA control chart and CUSUM control chart are related to parameters \( b \) and \( n \), as well as the variance of each source of variation. When the parameters \( b \) and \( n \) are constant, since \( \sqrt{\frac{r}{2-r}} > 1 \), then according to the calculation formula of the second kind of probability \( \beta \): the same process: \( \beta_E < \beta_C \). It can be seen in table 4, \( \lambda \) within 0.05 ~ 0.25 and \( K = 3 \) or so has good effect, engineering practice generally take \( \lambda = 0.05, \lambda = 0.05 \) or \( \lambda = 0.20 \). At the same time, when there is no deviation, i.e. \( L\sigma = 0 \), the ARL value of the two control charts is equal, but when there is deviation, i.e. \( L\sigma > 0 \), the ARL value of the EWMA control chart is significantly lower than the latter (the smaller the deviation is, the more obvious), which indicates that the EWMA control chart has higher detection force and shorter average running length.

Table 4. Comparative analysis of EWMA and CUSUM control charts

| Control charts | Offset (Lσ) | 0.0035 | 0.0356 | 0.0748 | 0.2877 | 0.5103 | 0.7639 | 0.9257 |
|----------------|-------------|--------|--------|--------|--------|--------|--------|--------|
|                | \( \varphi = 0 \) | \( \varphi = 0.5 \) | \( \varphi = 1 \) | \( \varphi = 1.5 \) | \( \varphi = 2.0 \) | \( \varphi = 2.5 \) | \( \varphi = 3.0 \) |
| EWMA ARL K=3.054, \( \lambda = 0.40 \) | 500 | 71.2 | 14.3 | 5.9 | 3.5 | 2.5 | 2.0 |
| EWMA ARL K=2.998, \( \lambda = 0.25 \) | 500 | 48.2 | 11.1 | 5.5 | 3.6 | 2.7 | 2.3 |
| EWMA ARL K=2.962, \( \lambda = 0.20 \) | 500 | 41.8 | 10.5 | 5.5 | 3.7 | 2.9 | 2.4 |
| EWMA ARL K=2.814, \( \lambda = 0.20 \) | 500 | 31.3 | 10.3 | 6.1 | 4.4 | 3.4 | 2.9 |
| EWMA ARL K=2.615, \( \lambda = 0.05 \) | 500 | 28.8 | 11.4 | 7.1 | 5.2 | 4.2 | 3.5 |
| CUSUM Detection power | 0.0035 | 0.0356 | 0.0748 | 0.2877 | 0.5103 | 0.7639 | 0.9257 |
| CUSUM ARL | 370.38 | 81.22 | 14.97 | 4.41 | 2.00 | 1.29 | 1.07 |

According to the above three kinds of control chart analysis in practical application, as shown in Figure 2, set \( \lambda = 0.3 \), control temperature of asphalt mixture and asphalt weight average \( X \)-EWMA control chart.
As can be seen from Figure 2, the points on the EWMA control chart contain the historical information of the previous data, and the smaller migration process can be detected with better ARL value. In this case, the fluctuation of the mean value cannot be detected using the traditional Shewhart control chart, while the CUSUM control chart requires a longer detection run length.

5. conclusions and prospects
Based on the mathematical model of multiple sources of variation and the statistical process control analysis theory, and based on the index analysis results of asphalt mixture for highway pavement construction, this study compared and analyzed the applicable scope, running length, detection ability and other characteristics of common quality control charts. In the construction of Yuxi section of Yuanman Expressway, asphalt mixture temperature and asphalt weight indexes were selected to carry out sample data collection and practical analysis. The results show that the influence factors of multiple variation sources are not considered for the general conventional control chart of Hughart. Under the influence of multiple variation sources, the detection force of EWMA control chart is higher and the average running length is shorter than that of CUSUM control chart with the increase of mean offset.

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