Application of Dynamic Control Theory in Intelligent Control System for Asphalt Pavement Construction

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Abstract. The intelligent control system for asphalt pavement construction can achieve the data collection, transmission, analysis and early warning during the entire construction process, including mixing, transporting, paving and rolling, by installing data collecting equipment and building the remote monitoring platform. It can effectively improve the construction quality control level. However, the quality control method adopted by the system still has some shortcomings and can't meet the requirements of dynamic quality control. Therefore, this paper infuses dynamic control theory to improve the existing system quality control method. And, the practicability and effectiveness of the proposed method are verified through case analysis in this paper.

Keywords: Asphalt pavement, construction quality control, dynamic control theory.

1. Introduction

Quality control level of asphalt pavement construction is the key factor affecting the final highway quality. At early period, construction quality control is mostly by manual. With the continuous improvement of quality control theory and the accumulation of practical experience, the level of construction quality control has been effectively improved, but manual control methods will inevitably be lacking in terms of timeliness, precision, refinement, and economy. In recent years, with the integration of information technology and highway fields, many projects have begun to apply intelligent control systems for asphalt pavement construction, which using information technology to strengthen the collection, analysis, and feedback of construction quality information, effectively improving construction quality control level [1]. However, these systems still have some shortcomings in the early warning mechanism for quality control. They are too sensitive to abnormal phenomena in the construction process, so that once the construction data does not meet the set normal value, an early warning will be generated without effectiveness, since it does not take into account that the construction quality control of asphalt pavement is a dynamic process. Therefore, this paper introduces dynamic control theory to optimize the existing quality control method, so as to achieve the purpose of effective and stable control of pavement construction quality.
2. Intelligent control system for asphalt pavement construction

2.1 System introduction
The intelligent control system for asphalt pavement construction is developed based on information technology such as the Internet of Things, sensors, and high-precision positioning, which is used to replace manual monitoring of various construction stages, so as to realize the real-time collection, analysis, evaluation and early warning of abnormal data in the whole process of mixing, transporting, paving, and rolling. Meanwhile, the system has the function of real-time displaying the working status of construction machinery, working position and project progress [2].

a) By installing sensors, radio frequency, positioning and other data acquisition and control equipment on the corresponding mixing machine, transporting vehicle, paver, and roller, the measured data, time data and temperature data in the mixing stage, the vehicle information and transportation time in the transporting stage, the paving temperature and paving speed in the paving stage, and the rolling times, rolling temperature and rolling speed in the rolling stage, are all collected in real time and uploaded to data center for analysis [3].

b) Remote control analysis platform is built to storing, calculating and analyzing the collected data in each stage, together with a three-level early warning mechanism, which is used to real time control the key quality control indexes, realizing the traceability of pavement quality problems [4].

2.2 Existing problems of intelligent control system
The feedback and early warning mechanism is the core of the intelligent control system of asphalt pavement construction. Based on the real-time acquisition of quality control key data for each construction stage, a three-level early warning mechanism has been set up for these quality control indexes, with clear warning limit parameters for different levels. When the real-time monitoring construction data exceeds its warning limit, the system will start the warning and give timely feedback to the personnel in site for adjusting construction technology [5]. But the limit parameter set by this early warning method is an empirical value. Once the data exceeds the limit, it will be judged as an abnormality and an early warning will be generated, with certain limitations and problems as follows:

a) When the quality control index data performs large continuous fluctuations and frequently approaches but does not exceed the warning limit parameters, the construction quality has been affected already. However, the system cannot effectively judge this abnormal situation.

b) When there is only a small amount of discontinuous quality control index data exceeding the warning limit parameters, the construction quality will basically not be affected, but the system will still determine the construction abnormal.

c) Due to the complex influence of materials, environment and other factors, the quality control index data may exceed the warning limit, but these situations are still qualified. In this case, the system will just give a warning, without effectively distinguishing.

3. Application of dynamic control theory
In order to solve the above problems, optimize the system control method, and improve the stability of construction quality, a quality control method based on dynamic control theory is proposed in this paper.

3.1 Construction quality variation and influencing factors
Asphalt pavement construction is a dynamic process affected by human, machine, material, method, environment and other factors. There are many factors causing construction abnormalities, which can be roughly divided into accidental factors and systematic factors [6]. Accidental factors occur randomly during the construction process and have little impact on the construction quality, while systematic factors are caused by internal reasons in the construction process. The data impact of these two factors on the construction quality is performed as exceeding or lower than the normal data. But
the difference is that the abnormal data caused by accidental factors are mostly small and discontinuous, which has little impact on the construction quality, while the abnormal data caused by systematic factors are mostly continuous large-scale abnormal data. In order to effectively implement process quality control, it is necessary to identify whether the process is in a normal state or an abnormal state. However, the current early warning methods applied in intelligent control systems cannot effectively judge these two states, so the construction quality control is not ideal. For effectively judging and analyzing the states, dynamic control theory can provide a good solution.

3.2 Normal distribution
Dynamic control theory is based on statistics. Therefore, before dynamic control theory is introduced, the distribution of quality control indexes for asphalt pavement construction needs to be analyzed to judge whether they meet statistically typical distributions, such as normal distribution, T distribution and Poisson distribution.

Among them, the normal distribution is uniquely determined by the average value and standard deviation of the quality control indexes. The average value and standard deviation can well reflect the uniformity and consistency of the test results, so as to analyze the data changes in construction process.

For further verifying whether the distribution of the key indexes of construction quality control conforms to the normal distribution, so as to carry out the dynamic control method, this paper monitors, analyzes and summarizes the data of asphalt aggregate ratio and rolling temperature, collected by the intelligent control system in real time. Table 1 lists the average and standard deviation of asphalt aggregate ratio, with the corresponding histogram and the fitted ideal normal distribution curve, shown in Figure 1.

From Table 1, and Figure 1, it can be seen that the distribution of key indexes for asphalt pavement construction quality control is basically a normal distribution, so it is reasonable to apply the normal distribution related conclusions in quality dynamic control.

| Index                          | Sample size | Average | Standard deviation |
|--------------------------------|-------------|---------|--------------------|
| Asphalt aggregate ratio (%)    | 200         | 5.85    | 0.063              |

Figure 1. Histogram and fitted ideal normal distribution curve of asphalt aggregate ratio.

3.3 Dynamic control theory
The quality of pavement construction is affected by accidental factors and inevitable factors alone or together, performing two different states, either control state or instability state. Quality dynamic control theory is to use statistical knowledge to determine whether the current construction quality control is out of control or not, by drawing control charts of quality indexes and analyzing their fluctuations, and then make corresponding construction process adjustments after analysis.
The quality control chart is constructed following the principle of normal distribution with control limits. Figure 2 is a quality control schematic diagram. As shown in Figure 2, UCL and LCL are the upper and lower control limits of quality control, respectively. And CL is the ideal value of the quality index, which is the target value of quality control as well.

![Quality Control Schematic Diagram](image)

**Figure 2.** Quality control schematic diagram.

3.4 Application of dynamic control theory

Because the existing quality control methods used in intelligent control system cannot better judge the state of the construction quality, this paper introduces an improved average-standard deviation control chart ($\bar{X}$-$R$) to analyze and control construction quality state.

a) Draw quality control chart. Take the construction quality index data collected by the intelligent control system at a certain time as base, and move forward until data size being N, so as to compose a sample group. And then, a quantity of sample groups are used to build a sample library. Finally, the $\bar{X}$-$R$ control charts are drawn.

b) Movable quality control line. The application of dynamic control theory to asphalt pavement construction control also faces the problem that quality control line is changing all the time, due to the influence of environment and other external factors. In this case, the quality control limit of the previous time period is used to control the next period, so as to obtain the quality control line, which continuously and dynamically changes with time.

c) Judgement of quality control state. For the drawn $\bar{X}$-$R$ control chart, it is necessary to analyze and judge the construction quality states. There are four common states, which are ideal control state, average drift state, wide dispersion state, and out of control state, respectively.

4. Case application and analysis

The intelligent control system for asphalt pavement construction has already realized real-time monitoring of quality control index data in the stage of mixing, transporting, paving, and rolling. In order to verify the practicability of the dynamic quality control method proposed in this paper, the real-time collected asphalt aggregate ratio data and rolling temperature data are selected for case analysis, in which, the sample group size N is 25.

4.1 Quality control of asphalt aggregate ratio

Figure 3 is the chart of part of the asphalt aggregate ratio data collected by the intelligent construction system. Figure 4 are average control chart and range control chart of asphalt aggregate ratio, respectively.

It can be seen from Figure 3 that at around 8:41 am, a sudden change of data appears, exceeding the warning upper limit. At this time, the intelligent control system will issue a corresponding warning message to users, but in the actual production process, the data at this point does not affect the overall construction quality.

It can be seen from Figure 4 that the average value of the normal distribution of the asphalt aggregate ratio basically coincides with the target value, and the sample range is small, showing that
the control of asphalt aggregate ratio is in the ideal state. Besides, the quality dynamic control method has good robustness when dealing with sudden change data. Taking the sudden change data at around 8:41am for example, the original method used in system will send for early warning, while the method proposed in this paper will have no warning in line with the actual production situation.

Figure 3. Asphalt aggregate ratio collected by intelligent construction system.

Figure 4. Average and range control chart of asphalt aggregate ratio by X-R.

4.2 Quality control of rolling temperature
Figure 5 is the chart of part of the rolling temperature data collected by the intelligent construction system. Figure 6 are average control chart and range control chart of rolling temperature, respectively.

Figure 5. Rolling temperature collected by intelligent construction system
It can be seen from Figure 5 that the rolling temperature is frequently approaching the warning lower limit, indicating that the construction quality control is not stable. The original method used in the system cannot identify this phenomenon, and will just regard it as a normal state so that misjudgment occurs.

It can be seen from Figure 6 that before 14:04pm, the average value and the range of the normal distribution of the rolling temperature is basically the same as the target value. At this time, the rolling temperature control is in the ideal state. But after 14:04pm, the average value of the rolling temperature starts to fluctuate. Although the overall value is still near the target value, the range becomes larger, deviates from the target value and exceeds the upper control limit, which indicates that compared to the previous data, the current rolling temperature fluctuates greatly and changes the ideal state to the wide dispersion state. In this case, it is necessary to investigate the specific reasons and adjust the construction process appropriately.

5. Conclusions
Intelligent control system is an organic integration product of information technology and traditional highway engineering, by using the real-time, accurate, and efficient characteristics of information technology, so as to promote the fine control of the entire process of asphalt pavement construction, including mixing, transporting, paving, and rolling, whose three-level early warning mechanism could improve the quality control level of the construction team to a certain extent. But this method has limitations and problems. This paper analyzes the data distribution of asphalt aggregate ratio, and rolling temperature for asphalt pavement construction, introduces dynamic control theory, optimizes the quality control method, and makes comparison as well as case analysis of key indexes to verify the practicability and effectiveness of the dynamic quality control method. The results indicate that it well improves the practicability and effectiveness of the existing intelligent control system, and have great significance for further promotion and application.

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