Research on pavement quality control based on bayes' theorem

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Abstract: In order to meet the fine construction requirements of municipal engineering, improve the pavement stone paving technology level. Through the statistics of municipal engineering sidewalk construction common technical quality problems. Established the pavement surfacing technology quality control index system, and establish the quality control of causal relationship between spatial topology relationship structure model, using the mature of bayes' theorem to the pavement stone pavement quality control study, forecast the quality of each control factor to influence the quality of the pavement stone pavement, the size of the causal backstepping method is used to analyze mechanism of quality control factor, finally, complete quality control evaluation by mutual information theory, find out the biggest quality control factor. Taking the project of yanjiang avenue (minsheng road to qingchuan bridge) in wuhan as an example, this paper applies bayes' theorem and mutual information theory to the research of municipal pavement quality control. The results show that the probability of stone pavement quality accidents in this project is 2.83%, the roadbed quality control is not in place is the largest quality control factor affecting the fine construction of this project.

1. Introduction
With the rapid development of urban traffic construction, the quality requirements of municipal engineering are constantly improved. Has more limitation existing construction technology, the engineering general situation is not the same, the pavement as accessory works on either side of the road section, is the carrier of infrastructure and the overall environment, the construction craft looks be like simple, but achieve "extreme" quality requirement is not easy, it requires construction personnel in the pavement construction, the construction every procedure should be in strict accordance with the specification, test for every quality control points, at the same time, construction and quality supervision personnel close cooperation. In addition, in the process of sidewalk construction, the risk of quality accidents shows an increasing trend. Therefore, it is of guiding significance to carry out research on pavement quality control for improving the refinement level of pavement construction[1].
Domestic evaluation methods mainly use medical diagnosis, construction safety, urban tunnel, hydraulic dam and other safety aspects of the evaluation research, the municipal pavement quality control of stone. These scholars usually adopt traditional methods such as support vector machine method, particle swarm optimization method and fuzzy function method. In the uncertainty analysis, the biggest limitation of these methods is that the calculation accuracy varies greatly in the dynamic evaluation system. At the same time, the pavement quality accident is not a single quality control factor, is often a number of quality control factors related to the coupling of quality accidents. This requires us to search for new evaluation methods to study the uncertain problems.

2. Introduction to bayes' theorem
Bayes' theorem relies on digital model, which can rely on powerful digital logic reasoning calculation function and intuitively express the advantages of model calculation results in a digital way, and is highly praised in terms of uncertainty analysis and reasoning problems.

Bayesian network model itself is a vector graph of boundary conditions, and these variable nodes are connected with nodes to form directional arcs. Suppose that in the directed arc, there is a node F pointing to node P, then F controls P. We call F the parent node and P the child node. If node F has only unique children, we call F the root node.

In probability theory, conditional probability formula is used to express that if a node has no parent node, prior knowledge probability is adopted for data expression. At this time, root node is prior probability, and other nodes take root node as the conditional probability distribution function formed by boundary condition. Is denoted as $P(U_i|U PI I)$, and $U PI I$ is the value of the parent node, and the nodes $U_1, U_2...$ The probability of $Un$ is multiplied to get the corresponding joint distribution probability.

3. Study on the quality control of pavement stone pavement by bayes' theorem
In the study of pavement quality control based on bayes' theorem, the quality control process can be divided into the following five steps:

(1) quality risk identification. On the basis of collecting quality risk related information from natural risk, technical risk, management risk, environmental risk and other aspects, gather personnel engaged in all aspects of project implementation and with knowledge of all aspects to participate, and summarize the results of risk identification into quality risk identification report. List the possible quality control factors of the project in the form of a list, and finally determine the final quality control factor through the discussion of the expert group.

(2) establish bayesian network model. Based on the determined final quality control factors, the causal relationship of the quality control factors is determined according to the standard construction process of pavements, and then the spatial topological relationship structure model of the causal relationship of quality control is drawn. According to the spatial topological relationship model, the basic parameters of bayesian network are determined. The noisy-gate model is used to determine the CPT of the whole bayesian network model.

(3) risk reasoning. The probability of quality control factors and the main causes of quality accidents are calculated through causal inference and diagnostic inference based on the established bayesian network model.

1) causal reasoning.

The conditional probability of calculating risk factors can be divided into two kinds: the conditional probability without evidence and the conditional probability of evidence. The probability of quality control factors is forecasted in advance. Before the construction starts, the construction side takes technical measures to reduce the occurrence of quality accidents.

If in the process of pavement stone paving, the set composed of all known quality control factors $U_i$ has no evidence of $U_l$, the probability of quality accident occurrence of node $R$ is calculated as follows:

$$P(R=Y/U_l)=P(R/Y|U_1=X_1,U_2=X_2,...,U_n=X_n), \quad U_l \in U_t, \quad U_i \in \{R,N\}$$

Where, $n$ is the number of nodes, and each node has two different states (Y, n).K means the occurrence of node events, and n means the non-occurrence of node events.
2) diagnostic reasoning.
Under the condition that the quality accident result is known, the quality control factor is found and the posterior probability is determined by the calculation and analysis of the bayesian network model. If the posterior probability distribution of each child node occurs in the state of node R (quality control factor), the posterior risk probability of the Ui of the ith node is calculated as follows:

\[ P(U_i=Y|R=Y)=\frac{P(U_i=Y)P(R=Y|U_i=Y)}{P(R=Y)} \]

(4) correlation coupling analysis. The correlation degree of parent node to child node is calculated by mutual information theory.

(5) risk control. The key quality control factors of the quality accident risk are determined based on the evaluation results analyzed in the study of pavement quality control, and measures are taken to control the accident risk in time.

4. Engineering case analysis
By collecting case data and expert analysis reports of the pavement stone pavement quality accident of municipal engineering, the paper studies the pavement stone pavement quality control based on bayes' theorem. The specific process is as follows[5].

4.1 identification of risk factors
According to the research results of relevant municipal engineering and the quality accident analysis report, combined with the construction project of yanjiang avenue (minsheng road to qingchuan bridge) contracted by wuhan municipal construction group co., LTD., the statistical analysis of 20 quality control factors for pavement pavement of municipal engineering in mainland China is shown in table 1.

Table 1 statistical information of quality control factors

| classes   | participants | factor                          | Rank |
|-----------|--------------|---------------------------------|------|
| 1         |              | drawings                        | Y1   |
| 2         |              | money                           | Y2   |
| 3         |              | Design changes                  | Y3   |
| 4         |              | exploration report              | S1   |
| 5         |              | Design scheme                   | S2   |
| 6         |              | Skill level                     | C1   |
| 7         |              | Raw material quality            | C2   |
| 8         |              | inspection management           | C3   |
| 9         |              | Construction machinery selection| C4   |
| 10        |              | product protection measures     | C5   |
| 11        |              | irregularities                  | C6   |
| 12        |              | Subgrade quality control        | C7   |
| 13        |              | Mortar grain gradation          | C8   |
| 14        |              | Curing time                     | C9   |
| 15        |              | Surface quality control         | C10  |
| 16        |              | Construction technology disclosure| C11|
| 17        | supervisor   | quality supervision             | J1   |
| 18        |              | implementation efficiency       | J2   |
| 19        |              | Underground pipeline            | H1   |
| 20        | environment  | Adjacent building               | H2   |

4.2 establishment of bayesian network model
After determining the quality control factors mentioned above, the causal coupling relationship between quality control factors is analyzed. Thus, the basic nodes of the bayesian network model are set, and each node state is divided into Y and N, as shown in figure 1, which reflects the topological structure model of pavement quality control. In March 2019, there were quality problems in the stone paving of
longwang temple section of yanjiang avenue (minsheng road ~ qingchuan bridge) project. According to preliminary analysis, the finished product protection measures were not in place and the mortar particle gradation did not meet the requirements. The reason for the quality accident was that the construction technology was not disclosed before construction.

Figure 1. Bayesian network topology model

The initial probability of root node and the corresponding probability of child node are obtained by expert scoring method. The statistical results are compared and analyzed, and the final initial probability of root node is determined by calculation, as shown in table 2. The CPT of the sub-nodes is calculated using the noisy-gate model. For example, given that the connection probability between the child node C1 and its parents Y1 and J1 is 27% and 32% respectively, the calculation results of C1's conditional probability statistics are shown in table 3.

Table 2 original probability of root node

| factor     | H1 | Y1 | Y2 | C1 (%) |
|------------|----|----|----|--------|
| state      | Y  | N  | Y  | 1.86   |
|            | N  | Y  | N  | 98.14  |
|            | Y  | N  | Y  | 2.79   |
|            | N  | Y  | N  | 97.21  |
|            | Y  | N  | Y  | 8.41   |
|            | N  | Y  | N  | 91.59  |
|            | Y  | N  | Y  | 7.53   |
|            | N  | Y  | N  | 92.47  |

Table 3 CPT of child node C1

| factor | Y1 | Y2 | C1 (%) |
|--------|----|----|--------|
| state  | Y  | N  | 58.46  |
|        | N  | R  | 29.48  |
|        | R  | N  | 48.12  |
|        | N  | R  | 0      |
|        | R  | N  | 41.54  |
|        | N  | R  | 70.52  |
|        | R  | N  | 51.88  |
|        | N  | R  | 0      |

4.3 forward inference of causal reasoning risk

The root node in the bayesian network is imported into its occurrence probability, as shown in table 2. Then the prior probability of other child nodes is calculated. Bayes' theorem is used to obtain the prior probability P (R=Y) =2.83% of pavement stone paving, which indicates that the pavement quality accident of this project is at a relatively low level. Will import of evidence, the evidence will be through the moving forward of the bayesian network topology, so as to calculate the interaction between the different quality control factors and the quality accident probability are shown in table 4, such as the quality control of the pavement stone pavement evaluation study, known J1, P import certificates in bayesian network (J1 = Y) = 1, is pushing method causal reasoning quality accident probability is 4.46%.

Table 4 probability of pavement quality accident prediction

| classes    | evidence | Probability value (%) |
|------------|----------|-----------------------|
| priori knowledge | Nothing  | 4.46                  |
| posteriori knowledge | P(H1=Y)=1 | 3.68                  |
|             | P(Y3=Y)=1 | 4.12                  |
The results show that when quality control factor H1 does not occur, the overall quality accident probability is very low. When multiple control factors are coupled, the overall quality accident risk increases much more than the single factor. It shows that the quality control factors in the established bayesian network model are positively correlated with the final quality accidents\(^6\).

### 4.4 reasoning and diagnosis risk by backward inference

The posterior marginal probability of each quality control factor is calculated by using the diagnostic inference function of bayes' theorem. The specific data are shown in table 5. The posterior probability value can qualitatively determine the degree of control of quality control factors for risk events.

If quality accidents occur in the process of pavement stone paving, the posterior probability of reverse diagnosis by table 5 shows that the construction machinery selection does not meet the requirements \((P(C4=Y|R=Y)=28.46\%)\) ranks higher, which is the most likely factor of this accident. Therefore, after the occurrence of the subway construction risk accident, the accident investigation of this factor should be carried out in priority. If it is true that \(P(C4=Y)=1\) is determined this time, the construction unit shall take timely and effective measures to prevent further deterioration of the event. When C4 factor is controlled, risk diagnosis is carried out again, and posterior probabilities of other nodes are calculated by backward reasoning, as shown in figure 2. At this time, it is found that the probability value of C11 (disclosure of construction technology) is the largest, which is 19.56\%. Subsequent quality control starts from C11, followed by the investigation result of C11, new evidence is introduced in BN for the third backward diagnosis. In accordance with the continuous cycle of this process, the probability of quality accident is reduced to the maximum to meet the requirements of fine construction\(^7\).

![Figure 2 quality factor diagnosis results](image)

**Table 5 basic information of quality factors**

| classes | priori (%) | posteriori (%) | MI/×10\(^6\) | Rank |
|---------|------------|----------------|-------------|------|
| Y₁      | 11.68      | 13.44          | 176         | 7    |
| Y₂      | 4.46       | 3.66           | 145         | 13   |
| Y₃      | 0.98       | 9.72           | 121         | 17   |
| S₁      | 1.45       | 6.34           | 196         | 1    |
| S₂      | 2.21       | 3.49           | 174         | 9    |
| C₁      | 11.21      | 5.23           | 184         | 3    |
| C₂      | 7.84       | 14.21          | 180         | 5    |
### 4.5 Prediction of Quality Risk by Mutual Information Theory

Based on mutual information theory, the corresponding mutual information (MI) values of each quality control factor can be calculated. The detailed data are shown in Table 5. The mutual information value can qualitatively reflect the degree of quality accident control by control factors. It can be seen from the information table that S1, C11 and C1 have a stronger control effect on pavement quality and should focus on strengthening supervision and management.

### 5. Conclusion

In order to meet the fine construction requirements of municipal engineering, improve the pavement stone paving technology level. Through the statistics of municipal engineering sidewalk construction common technical quality problems. Established the pavement surfacing technology quality control index system, and establish the quality control of causal relationship between spatial topology relationship structure model, using the mature of bayes’ theorem to the pavement stone pavement quality control study, Wuhan municipal construction group co., LTD., built along the river road (civil rights road ~ qingchuan bridge) engineering construction projects, and statistical analysis to mainland China municipal engineering abroad, 20 quality control factors of pavement stone pavement, prediction exploration report, construction technical clarification, homework personnel technical level to influence the quality of the pavement stone pavement. In the process of construction, measures should be taken to focus on control.

### References

[1] ZHANG Li-Mao, CHEN Hong-Yu, WU Xian-Guo 2011 Research on decision support method of safety management in complex engineering based on bayesian network Chinese journal of security science 21(4): 140L142.

[2] GAO Hui, YAN Fei, LI Kai-Cheng 2011 Application of bayesian network in safety analysis of rail transit screen door system Research on urban rail transit 24(1): 46L47.

[3] WANG Lu-Jie 2017 Application of bayesian network in subway construction safety evaluation Municipal technology 9(2): 99L101.

[4] HE Li-Hua, WEI Qi, 2017 Fire risk assessment of building construction based on fault tree and bayesian network Journal of engineering management 2(1): 101L107.

[5] SHI Lei, LIU Jun-Zhou, WEI Wan-Wan 2019 Research on simultaneous interpolation and amplitude preserving denoising of prestack data based on bayesian inversion Advances in geophysics 6(12): 618L631.

[6] WANG Hai-Yu, 2019 Local bayesian network structure search algorithm based on node block sequence constraints Journal of automation 9(2):4L6.

[7] XU Man,GAN Dan 2018 Bayesian-case retrieval feature selection model based on mutual information Industrial engineering and management 8(21):176L182.