Correlation analysis of highway asphalt pavement distress based on Spearman correlation coefficient

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Abstract. In order to improve the operational life of highway asphalt pavements, reduce urban traffic safety accidents, and improve pavement travelling comfort, this paper analyze the frequency of different highway asphalt pavement distresses and calculates the percentage of each other based on highway asphalt pavement data sets in Shandong. The results showed that the five types of highway asphalt pavement distresses including alligator cracks, longitudinal cracks, transverse cracks, sealed cracks and patches occur with high frequency and account for 96.2% of the total proportion. For revealing the coupling principle between different highway asphalt pavement distress, this paper analyze the correlation between the five types of highway asphalt pavement distresses by Spearman correlation coefficient. The results showed that alligator cracks have a higher positive correlation with transverse cracks and longitudinal cracks and sealed cracks have a negative correlation with transverse cracks. The research findings are helpful to understand the characteristics of pavement distress conditions more clearly and to optimize the level of service of asphalt pavements on urban roads.

1. Introduction

Roads are one of the key components of urban transport infrastructure, which is crucial for urban development, population mobility and economic prosperity. By the end of 2022, the total mileage of highways in China has reached 5,354,800 kilometres. Road transport accounted for 63.5% of passenger traffic and 73.3% of freight traffic. More than 95% of China's highway use the form of asphalt pavement. Because of the repeated action of vehicle loads, complex natural factors, engineering quality and other factors of common influence\cite{1,2}, the pavement will appear cracks, potholes and other asphalt pavement distresses. These distresses appearing on the asphalt pavement directly threaten the normal use of the road, affecting the safety and comfort of travelling, and also have a non-negligible negative impact on the economic development of the city.

Many scholars have studied the types, causes, mechanisms and specific control measures of the distress\cite{3-5}. Zhou et al.\cite{6} analyzed the characteristics, distribution and morphological features of highway cracks and found that the type of cracks on asphalt pavement has a certain correlation with the pavement distress rate and the influence of longitudinal cracks and cracks on the pavement distress rate is larger than that of transverse cracks.

Based on LTPP data, He \cite{7} reveals that the original distress record of asphalt pavement is actually a large sparse matrix containing a large number of zero values.

Xia\cite{8} studied the degree of correlation between crack-like distresses in cement concrete pavements by Pearson's correlation coefficient and the results show that the correlation between repaired cracks is higher than that between nascent cracks. Li et al.\cite{9} used association rules to mine the relationship between different types of asphalt pavement distresses and concluded that asphalt pavement distresses are both independent of each other and cause each other to produce. Some studies\cite{10-11} have shown that Spearman correlation coefficient is better than Pearson's correlation coefficient in dealing with missing values and outliers in continuous data.

In this study, the correlation coefficient of Spearman correlation coefficient is used to analyze the correlation between different types of asphalt pavement distresses. The interrelationships between different distresses are explored and to provide a basis for levels of service on urban roads are optimized the maintenance of urban asphalt pavements.

2. Correlation analysis methods for asphalt pavement distresses on highway

During the operation of highways, asphalt pavements are distresses to a certain extent due to temperature, rainfall and vehicle loads. According to the highway technical condition assessment standards, there are 11 types of
distresses to asphalt pavement such as alligator cracks, block cracks, longitudinal cracks, transverse cracks, potholes, raveling, subsidence, rutting, corrugations, bleeding and patching. For revealing the coupling principle between each distress, this paper analyzes the pavement distresses and the correlation between each other based on pavement distresses data sets for different areas.

The commonly used correlation analysis methods are Pearson correlation coefficient, Kendall correlation coefficient and Spearman correlation coefficient. Pearson correlation coefficient has good ability to capture linear correlation, but has poor performance in nonlinear correlation noise. Kendall correlation coefficient is used as a nonparametric statistic to measure the degree of correspondence between two ordered series. Gaussian noise Kendall correlation coefficient does not require the distribution of the variable data and is insensitive to erroneous data and extreme values, so Spearman correlation coefficient is used to measure the degree of correspondence between two ordered series of non-parametric statistics, and Gaussian noise is relatively conservative. Spearman correlation coefficient does not require the distribution of the variable data and is insensitive to erroneous data and extreme values, so Spearman correlation coefficient is selected for correlation analysis between pavement distresses.

Spearman correlation coefficient is defined as Eq. (1)\(^\text{[13]}\):

\[
\rho = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}}
\]

where, \(x_i\) and \(y_i\) are sample points in different characteristic columns and \(x\) and \(y\) are the standard deviations of \(x\) and \(y\).

Spearman correlation coefficient is calculated in the range of [-1,1], when \(\rho > 0\) indicates that the two indexes are positively correlated, \(\rho < 0\) indicates that the two indexes are negatively correlated, and \(\rho = 0\) indicates that the two indexes are not correlated at all, and the strength of correlation is generally characterised by five levels according to the absolute value of the Eq. (1) calculation results, and the specific levels are as shown in the Table 1.

Table 1. Degree of Spearman correlation coefficient.

<table>
<thead>
<tr>
<th>(\rho)</th>
<th>Degree of relevance</th>
</tr>
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<tbody>
<tr>
<td>0&lt;</td>
<td>(\rho</td>
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<tr>
<td>0.3&lt;(</td>
<td>\rho</td>
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<tr>
<td>0.5&lt;(</td>
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<tr>
<td>0.8&lt;(</td>
<td>\rho</td>
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<tr>
<td>(\rho=1)</td>
<td>Perfect correlation</td>
</tr>
</tbody>
</table>

3. Analysis of the correlation between asphalt pavement distresses on highway

3.1. Distresses probability analysis

The data used in this paper is the asphalt pavement distresses detection data of a highway in Shandong Province in 2019. For 46km, it includes all 11 types of asphalt pavement distresses, and the table shows the data form of 1km of it.

Table 2. 1km asphalt pavement distress data for a highway in Shandong Province, 2019

<table>
<thead>
<tr>
<th>Alligator cracks (m²)</th>
<th>Block cracks (m²)</th>
<th>Longitudinal cracks (m²)</th>
<th>Horizontal cracks (m²)</th>
<th>Subsidence (m²)</th>
<th>Sealed cracks (m²)</th>
<th>Patches (m²)</th>
<th>Rutting (m²)</th>
<th>Corrugation (m²)</th>
<th>Potholes (m²)</th>
<th>Raveling (m²)</th>
<th>Bleeding (m²)</th>
</tr>
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<tbody>
<tr>
<td>0.86</td>
<td>0.00</td>
<td>5.62</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>2.32</td>
<td>0.00</td>
<td>0.34</td>
<td>0.62</td>
<td>0.00</td>
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<td>0.00</td>
<td>0.06</td>
<td>0.00</td>
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<td>0.00</td>
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<td>0.00</td>
</tr>
</tbody>
</table>

As described in Table 2 alligator cracks, longitudinal cracks, transverse cracks, sealed cracks and patches occur more frequently, block cracks, potholes, and raveling occur less frequently, while subsidence, rutting, corrugation, and bleeding are non-occurring. Therefore this paper studies the asphalt pavement distresses are imbalance. When the existence of distress in a hundred metres is recorded as 1 time, the number of times a distress appears in 46km of pavement is recorded as the frequency of the distress. As shown in the Table 3 the frequency of all distresses are counted.

Table 3. Frequency distribution of asphalt pavement distresses and their percentages.

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alligator cracks</td>
<td>92</td>
<td>19.4%</td>
</tr>
<tr>
<td>Block cracks</td>
<td>1</td>
<td>0.2%</td>
</tr>
<tr>
<td>Longitudinal cracks</td>
<td>100</td>
<td>21.1%</td>
</tr>
<tr>
<td>Transverse cracks</td>
<td>98</td>
<td>20.7%</td>
</tr>
<tr>
<td>Potholes</td>
<td>14</td>
<td>3.0%</td>
</tr>
<tr>
<td>Raveling</td>
<td>3</td>
<td>0.6%</td>
</tr>
<tr>
<td>Sealed cracks</td>
<td>94</td>
<td>19.8%</td>
</tr>
<tr>
<td>Patches</td>
<td>72</td>
<td>15.2%</td>
</tr>
<tr>
<td>Total</td>
<td>474</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
As can be seen from the Table 3, the asphalt pavement distresses in the dataset studied in this paper are mainly alligator cracks, longitudinal cracks, transverse cracks, sealed cracks and patches of five types, of which patchings accounted for the largest proportion of all types of distresses, amounting to 35%, followed by longitudinal cracks, transverse cracks, and alligator cracks accounted for 21.1%, 20.7%, and 19.4% respectively. The proportion of these five types of distress was calculated to be as high as 96.2%, while the proportion of other types of distresses was less at only 3.8%. Therefore, alligator cracks, longitudinal cracks, transverse cracks, sealed cracks and patches are selected as the research objects.

In order to investigate the distribution pattern of the area affected by the five types of distresses the probability densities $H_i$ are calculated through Eq. (2),

$$H_i = \frac{X_i}{y \sum X_i}$$  

(2)

where, $x_i$ is the frequency of distress category $i$; $y$ is the set width of the horizontal coordinate.

From Fig. 1, it can be learnt that the area of alligator cracks is centrally distributed below 2m², accounting for 87.14%, which indicates that the alligator cracks of the pavement show a decentralized distribution. From Fig. 2, it can be learnt that the area of longitudinal cracks is distributed below 1.4 m², accounting for 91.41%, and it approximates a symmetrical distribution near 0.25 m². From Fig. 3, it can be learnt that the area of transversal cracks shows a decreasing trend. Fig. 4 shows that the area of sealed cracks is distributed below 2m², accounting for 97.33%, and Fig. 5 shows that the area of patches is concentrated below 0.4m², indicating that patches is mostly used to fill the smaller cracks.

Comparing with Fig. 1, 2, 3 and 4, it can be concluded that the area of alligator cracks, longitudinal cracks, transverse cracks and patches all show the characteristics of more distribution of small-area and less distribution of large-area. The distribution of the four diseases is roughly similar, whereas Fig. 4 shows that the area of sealed cracks is concentrated in the area less than 2m², which is different from the distribution of the other four kinds of distresses.

### 3.2. Correlation analysis between distresses

In order to further explore the correlation of the distresses, the Spearman correlation coefficient analysis method described in the previous section was used to correlate the statistical values of five distresses. The correlation coefficients between each distress were calculated as shown in Fig. 6. Fig. 7 shows the scatter plots and fitted curves between each distress. At the same time, the correlation between the distresses was obtained by combining the results of the analysis in 3.1.
In this paper, a comprehensive investigation and analysis of the common distresses of highway asphalt pavement was carried out, and the correlation between the distresses was explored through statistical methods and data analysis, and the following conclusions were drawn based on the Spearman correlation coefficient for the correlation analysis between the distresses:

1. Alligator cracks, longitudinal cracks, transverse cracks, sealed cracks and patches are the main distresses of highway asphalt pavement, of which patching in all types of the largest proportion of 35%, longitudinal cracks, transverse cracks, as well as alligator cracks accounted for close to the proportion of 21.1%, 20.7%, 19.4%, respectively and these five distresses accounted for 96.2% of all distresses.

2. Spearman correlation coefficient analysis shows that there is correlation between most of the existing asphalt pavement distresses, in which the correlation between alligator cracks and transverse cracks, alligator cracks and longitudinal cracks is the highest, and there is a negative correlation between sealed cracks and alligator cracks, sealed cracks and transverse cracks.

3. By calculating the probability of simultaneous existence between two distresses, it is concluded that when there is a large correlation between the existence of distresses, they will interact with each other and work together to shorten the service life of the road.

4. Conclusion

Combined with the Fig. 6 and Table 4, it can be seen that longitudinal cracks and transverse cracks affect the probability of alligator cracks, when alligator cracks occurs in the pavement, the probability of the existence of both longitudinal cracks is 47%, the probability of the existence of both transverse cracks is 51%. When there are longitudinal cracks and transverse cracks, the probability of the existence of alligator cracks cracking is 61% and 70% respectively, which indicates that in the case of longitudinal cracks and transverse cracks in pavement, the pavement is more likely to be alligator cracks cracked. Combined with the results of the correlation analysis, the large correlation coefficient between cracking and longitudinal and transverse cracks, there is the following conclusion: when there is a large correlation between the distresses, they will affect each other, and work together to shorten the service life of the road.

Table 4. Probability of coexistence between distresses.

<table>
<thead>
<tr>
<th></th>
<th>Alligator cracks</th>
<th>Longitudinal cracks</th>
<th>Horizontal cracks</th>
<th>Sealed cracks</th>
<th>Patches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alligator cracks</td>
<td>1</td>
<td>0.47</td>
<td>0.51</td>
<td>0.17</td>
<td>0.15</td>
</tr>
<tr>
<td>Longitudinal cracks</td>
<td>0.61</td>
<td>1</td>
<td>0.49</td>
<td>0.34</td>
<td>0.22</td>
</tr>
<tr>
<td>Horizontal cracks</td>
<td>0.70</td>
<td>0.43</td>
<td>1</td>
<td>0.50</td>
<td>0.31</td>
</tr>
<tr>
<td>Sealed cracks</td>
<td>0.23</td>
<td>0.51</td>
<td>0.57</td>
<td>1</td>
<td>0.27</td>
</tr>
<tr>
<td>Patches</td>
<td>0.31</td>
<td>0.33</td>
<td>0.09</td>
<td>0.11</td>
<td>1</td>
</tr>
</tbody>
</table>

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2. Spearman correlation coefficient analysis shows that there is correlation between most of the existing asphalt pavement distresses, in which the correlation between alligator cracks and transverse cracks, alligator cracks and longitudinal cracks is the highest, and there is a negative correlation between sealed cracks and alligator cracks, sealed cracks and transverse cracks.

3. By calculating the probability of simultaneous existence between two distresses, it is concluded that when there is a large correlation between the existence of distresses, they will interact with each other and work together to shorten the service life of the road.
In summary, there is a correlation between highway asphalt pavement distresses, which provides a certain basis for the prevention and repair of pavement distresses. In the future, we should further explore the influence mechanism of the causes of different distresses, take effective measures to reduce the occurrence and expansion of distresses, and improve the safety and comfort of urban highway use.

References