Impact of the Surge of Traffic Vehicles on the Traffic Safety of Yangtze River Tunnel

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Abstract. According to the uncertain and fuzzy characteristics of the tunnel traffic accident, the fuzzy comprehensive evaluation method based on the fuzzy mathematics is applied to evaluate the traffic safety of the tunnel. Finally, the impact of the surge of traffic vehicles on the safety of tunnel operation can be concluded by comparing the traffic safety evaluation results under the condition of smooth flow and congestion. The results show that the safety level of the tunnel is reduced to a moderate level from a good level. As a result, the risk of traffic accidents increases after the surge of the traffic vehicles in the Nanjing Yangtze River Tunnel. Effective measures should be taken to prevent the occurrence of traffic accidents. The measures of traffic diversion and vehicle classification management can be taken by Tunnel management department to prevent the occurrence of traffic accidents.

Introduction
The Nanjing Yangtze River Tunnel is the main path to ease the traffic pressure of the Nanjing Yangtze River, whose design value of daily traffic is 100000. During the closure period of the Nanjing Yangtze River Bridge, the average daily traffic volume of the Nanjing Yangtze River Tunnel exceeded 100,000 per day, exceeding its maximum design flow rate, which would most likely cause traffic congestion in the Nanjing Yangtze River Tunnel. Traffic accidents in the tunnel are more frequent, and traffic accidents are more likely to occur in the case of congestion[1]. Therefore, it is necessary to analyze the impact of the surge of vehicles in the tunnel on the traffic safety of the tunnel and give some suggestions on how to improve the tunnel traffic safety.

Domestic and foreign scholars[2-10]studied the traffic safety of highway tunnel operation from the perspective of safety level, accident probability and risk assessment respectively. There are many factors affecting tunnel traffic safety, and each factor has uncertainty and fuzziness. Considering that the fuzzy mathematics[11-13] can solve the fuzziness problem, the fuzzy comprehensive evaluation method was applied to evaluate the impact of the vehicle surge on the tunnel traffic safety was obtained.

Fuzzy Comprehensive Evaluation Model
The fuzzy comprehensive evaluation method includes the following steps[14]:
(1) Determine the weight of the indicator
The analytic hierarchy process (AHP) is used to determine the weight. AHP is shown in Fig.1.
(2) Set up a risk assessment collection
The evaluation collection is the set of judging results made by the evaluators for each evaluation. Generally, the evaluation levels can be divided into 4 levels or 5 levels according to the actual situation.

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(3) One-level fuzzy evaluation
Each member of the panel of experts is invited to evaluate each of the risk factors in turn according to the established rating criteria. On this basis, the evaluation matrix of single elements \( R_i \) in each subset \( B_j \) is respectively obtained.

\[
Y_i = W_i \cdot R_i = [y_{i1}, y_{i2}, \ldots, y_{in}]
\]  

(1)

The score of indicators of each guideline level is received by equation (2).

\[
P_i = Y_i * V
\]

(2)

(4) Two-level fuzzy evaluation
Based on the single-factor analysis results, the comprehensive evaluation matrix of each subset in \( A \) is obtained from equation (3).

\[
H = [Y_1, Y_2, Y_3, \ldots, Y_n]^T
\]

(3)

The final fuzzy comprehensive evaluation results of the project risk can be obtained by equation (4):

\[
B = W * H
\]

(4)

According to the evaluation results, the overall evaluation of the risk factors can be drawn by equation (5):

\[
P = Y * V
\]

(5)

Traffic Safety Analysis of Nanjing Yangtze River Tunnel

Analysis of Tunnel Traffic Accidents
Due to its closed, long but narrow, few exits characteristics of tunnels, it may result in serious damage in the event of an accident in tunnel. The main causes of tunnel traffic accidents are civil structures, traffic environment, mechanical and electrical facilities.

Nanjing Yangtze River Tunnel Characteristics
Since the official opening of the Nanjing Yangtze River Tunnel, the traffic volume has been increasing. According to the relevant statistical data, traffic data from January to November are shown in Table 1.
Table 1. Daily average vehicle flow of the Nanjing Yangtze River Tunnel.

<table>
<thead>
<tr>
<th>Time(month)</th>
<th>1~3</th>
<th>4~6</th>
<th>7~9</th>
<th>10~11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average daily traffic volume</td>
<td>4.08</td>
<td>5.04</td>
<td>6.00</td>
<td>10.20</td>
</tr>
</tbody>
</table>

(Ten thousand / day)

Traffic Safety Assessment Model of Nanjing Yangtze River Tunnel

Construct Index System

The tunnel traffic safety is affected by many factors such as people, environment and management. Based on the analysis of the causes of the tunnel traffic accidents and the characteristics of the Nanjing Yangtze River Tunnel, the evaluation index system of traffic safety of the Nanjing Yangtze River Tunnel was established mainly from the aspects of civil structures, traffic environment, electromechanical systems and accident management. The index system was shown in Table 2.

Table 2. Weight distribution of the traffic safety evaluation of the tunnel.

<table>
<thead>
<tr>
<th>Target level</th>
<th>Guidelines layer</th>
<th>Weight</th>
<th>Program floor</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil structure B1</td>
<td>Hole design C1</td>
<td>0.0769</td>
<td></td>
<td>0.3539</td>
</tr>
<tr>
<td></td>
<td>Pavement condition C2</td>
<td></td>
<td>0.0825</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Longitudinal slope C3</td>
<td></td>
<td>0.3420</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Road curve C4</td>
<td></td>
<td>0.2215</td>
<td></td>
</tr>
<tr>
<td>Traffic environment B2</td>
<td>Driving speed C5</td>
<td>0.5167</td>
<td></td>
<td>0.2797</td>
</tr>
<tr>
<td></td>
<td>Model proportion C6</td>
<td></td>
<td>0.0936</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traffic flow C7</td>
<td></td>
<td>0.6267</td>
<td></td>
</tr>
<tr>
<td>Operating System B3</td>
<td>Lighting System C8</td>
<td>0.1682</td>
<td></td>
<td>0.1128</td>
</tr>
<tr>
<td></td>
<td>Fire System C9</td>
<td></td>
<td>0.1822</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ventilation system C10</td>
<td></td>
<td>0.1822</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Monitoring system C11</td>
<td></td>
<td>0.0821</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Supply and Distribution System C12</td>
<td></td>
<td>0.2821</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Communication System C13</td>
<td></td>
<td>0.1586</td>
<td></td>
</tr>
<tr>
<td>Accident management B4</td>
<td>Management level of building C14</td>
<td>0.2382</td>
<td></td>
<td>0.4272</td>
</tr>
<tr>
<td></td>
<td>Traffic safety education C15</td>
<td></td>
<td>0.1581</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Daily inspections management C16</td>
<td></td>
<td>0.0585</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Information Release Capability C17</td>
<td></td>
<td>0.0962</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Emergency response capability C18</td>
<td></td>
<td>0.2599</td>
<td></td>
</tr>
</tbody>
</table>

Determine the Weight Set of Indicators

Ten experts including university researchers, tunnel designers, tunnel safety management personnel and other related profession were invited to compare the importance of each indicator and give the relative ratio to establish judging matrix $C \sim C_i$. 

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The corresponding eigenvectors of the judgment matrix were calculated through MATLAB by the steps shown in figure 1.

$$W = [0.0769, 0.5167, 0.1055, 0.0609]$$

$$W_1 = [0.3539, 0.0825, 0.3420, 0.2215]$$

$$W_2 = [0.2797, 0.0936, 0.6267]$$

$$W_3 = [0.1128, 0.1822, 0.1822, 0.0821, 0.2821, 0.1586]$$

$$W_4 = [0.4272, 0.1581, 0.0585, 0.0962, 0.2599]$$

CR of each matrix was less than 0.1, meeting the consistency test, and the weight of each indicator was shown in Table 3.

### Establish Tunnel Traffic Safety Rating Comment Set

Evaluation result of tunnel traffic safety is divided into five levels corresponding to the comment set, as shown in Table 3.

<table>
<thead>
<tr>
<th>security level</th>
<th>excellent</th>
<th>good</th>
<th>medium</th>
<th>bad</th>
<th>worse</th>
</tr>
</thead>
<tbody>
<tr>
<td>score(β)</td>
<td>85~100</td>
<td>70~85</td>
<td>55~70</td>
<td>40~55</td>
<td>0~40</td>
</tr>
</tbody>
</table>

### Nanjing Yangtze River Tunnel Traffic Safety Assessment

Ten experts from relevant experts were invited to form an evaluation team, including university researchers, tunnel designers and tunnel safety managers. The impact of the surge of traffic flow on traffic safety in Yangtze River tunnel after the closure of the Nanjing Yangtze River Bridge was obtained.

1. Traffic safety assessment of the Nanjing Yangtze River Tunnel before the closure of the bridge

Before the bridge was closed, the daily average traffic volume in the tunnel was about 60,000 vehicles / day. The traffic safety assessment matrix of the Nanjing Yangtze River Tunnel was acquired.

$$R_0 = \begin{bmatrix} 0.1 & 0.5 & 0.2 & 0.2 & 0 \\ 0.2 & 0.3 & 0.3 & 0.1 & 0.1 \\ 0 & 0.3 & 0.5 & 0.2 & 0 \\ 0 & 0.2 & 0.4 & 0.3 & 1 \end{bmatrix}, \quad R_1 = \begin{bmatrix} 0.3 & 0.4 & 0.2 & 0.1 & 0 \\ 0.5 & 0.3 & 0.1 & 0.1 & 0 \\ 0.4 & 0.4 & 0.1 & 0.1 & 0 \end{bmatrix}, \quad R_2 = \begin{bmatrix} 0.4 & 0.2 & 0.3 & 0.1 & 0 \\ 0.3 & 0.4 & 0.2 & 0.1 & 0 \\ 0.4 & 0.3 & 0.1 & 0.2 & 0 \end{bmatrix}, \quad R_3 = \begin{bmatrix} 0.5 & 0.3 & 0.1 & 0 \\ 0.3 & 0.4 & 0.2 & 0.1 & 0 \\ 0.4 & 0.2 & 0.2 & 0.1 & 0 \end{bmatrix}, \quad R_4 = \begin{bmatrix} 0.5 & 0.3 & 0.1 & 0 \\ 0.3 & 0.4 & 0.2 & 0.1 & 0 \\ 0.2 & 0.6 & 0.1 & 0.1 & 0 \end{bmatrix}$$

According to equation (1) ~ (2), the score of each criterion level was obtained.

$$P_1 = 68.71, P_2 = 77.97, P_3 = 74.60, P_4 = 75.56$$

The overall traffic safety evaluation of the Nanjing Yangtze River Tunnel before the closure of the Nanjing Yangtze River Bridge can be acquired from equation(3)~(5).

$$P = B \ast H = 76.09$$

Therefore, the traffic safety level of the Nanjing Yangtze River Tunnel was good before the bridge was closed according to table 4.
(2) Traffic Safety Evaluation of Yangzte River Tunnel after Bridge Closed

Traffic safety indicator layer evaluation matrix of Nanjing Yangtze River Tunnel after the closure of the Nanjing Yangtze River Bridge were shown as following.

\[
\begin{align*}
R_1 &= \begin{bmatrix}
0.1 & 0.5 & 0.2 & 0.2 & 0 \\
0.2 & 0.3 & 0.3 & 0.1 & 0.1 \\
0 & 0.3 & 0.5 & 0.2 & 0 \\
0.2 & 0.4 & 0.3 & 0.1 & 0
\end{bmatrix},
R_2 &= \begin{bmatrix}
0.1 & 0.3 & 0.4 & 0.2 & 0.1 \\
0.1 & 0.2 & 0.5 & 0.1 & 0.1 \\
0.2 & 0.1 & 0.6 & 0.1 & 0
\end{bmatrix},
R_3 &= \begin{bmatrix}
0.4 & 0.2 & 0.3 & 0.1 & 0 \\
0.3 & 0.4 & 0.2 & 0 & 0.1 \\
0.4 & 0.3 & 0.1 & 0.2 & 0 \\
0.3 & 0.3 & 0 & 0.2 & 0.2 \\
0.3 & 0.4 & 0.2 & 0.1 & 0 \\
0.4 & 0.3 & 0.2 & 0.1 & 0
\end{bmatrix},
R_4 &= \begin{bmatrix}
0.5 & 0.3 & 0.1 & 0 & 0.1 \\
0.3 & 0.4 & 0.2 & 0.1 & 0 \\
0.2 & 0.6 & 0.1 & 0.1 & 0 \\
0.3 & 0.6 & 0 & 0.1 & 0 \\
0.4 & 0.2 & 0.2 & 0.1 & 0.1
\end{bmatrix}
\end{align*}
\]

Under congestion conditions, the overall traffic safety rating of the tunnel was 70.19, the overall traffic safety of the tunnel decreased from good level to medium level. The traffic safety of the Nanjing Yangtze River Tunnel before and after the surge of traffic volume was shown in Table 5.

<table>
<thead>
<tr>
<th>Assessment indicators</th>
<th>Civil structure</th>
<th>Traffic environment</th>
<th>Operating System</th>
<th>Accident management</th>
<th>Overall safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>before</td>
<td>68.97(medium)</td>
<td>77.97(good)</td>
<td>74.60(medium)</td>
<td>76.09(good)</td>
<td></td>
</tr>
<tr>
<td>after</td>
<td>68.97(medium)</td>
<td>66.53(medium)</td>
<td>74.76(medium)</td>
<td>70.19(good)</td>
<td></td>
</tr>
</tbody>
</table>

It can be concluded that the traffic flow surge in the Nanjing Yangtze River Tunnel mainly affected the traffic environment of the tunnel and the traffic safety of the tunnel declined overall after the closure of the Nanjing Yangtze River Bridge. Effective measures were needed to divert traffic in the tunnel to prevent traffic accidents happening.

Conclusion

(1) Under normal traffic conditions, the traffic environment of the tunnel, operation system and accident management were all good. In other words, the tunnel speed, vehicle distance and vehicle proportion were all within an acceptable safety range. The firefighting equipment, ventilation system, lighting system and monitoring system were in normal operation. The tunnel owns a professional management team and agencies, which will ensure the normal operation of the tunnel.

(2) After the traffic flow of bridge was diverted to the Nanjing Yangtze River Tunnel, the traffic volume of the Nanjing Yangtze River Tunnel surged sharply and congestion occurred during peak hours. The traffic environment and operating system of the tunnel were all reduced from good level to medium level and the overall safety grade of tunnel traffic operation has been reduced to medium safety, the risk of tunnel accidents increasing.

(3) The level of tunnel traffic safety was decreased with the surge of the traffic flow in Nanjing Yangtze River Tunnel. Diversion measures should be taken such as choosing other crossing routes according to the drivers’ destination.

References


