Study on the Distribution Law and Speed Limit of Night Speed in Expressway Maintenance Area

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Abstract. In order to reasonably determine the maximum and minimum vehicle speed limit values at night and ensure the driving safety in the maintenance area of expressway, the distribution law of vehicle speed at night in the maintenance area of expressway is studied. Based on the investigation of one-way lane closure construction in the four-lane maintenance area of expressway, the location speed of the main traffic control area in the night maintenance area is analyzed, and the average speed, 85% vehicle speed, the speed difference in different areas and the speed difference in heavy-duty vehicle(HDV) and light-duty vehicle(LDV) workshops are determined. The results show that the standard deviation of vehicle speed distribution from warning area to transition zone to construction area is obviously reduced, and the speed difference between HDV and LDV is also obviously reduced. Finally, according to the distribution characteristics of night speed, the night speed limit model of maintenance operation area is given, the speed limit values of different models are calculated respectively, and the night perceived speed model is used to modify the speed limit value.

1. Introduction

Because of the closed lane, the traffic capacity of the expressway vehicle maintenance area will be reduced, which is easy to cause traffic accidents. Especially when driving at night in the maintenance area of expressway, the driver's vision will be reduced by about 50% [1]. According to statistics, the traffic accidents in the maintenance area at night account for about 60% of the total traffic accidents in the maintenance area. Therefore, it is of great significance to study the speed distribution and speed limit in the day and night expressway maintenance area.

At present, the existing literature has also studied the speed distribution law of each area in the expressway maintenance area. Bella [2] collected the driving simulator to study the night speed distribution. Meng [3] has made clear the speed distribution law of different types of maintenance areas of expressway through statistical analysis of measured speed data. At the same time, for the research on the speed limit of highway maintenance operation area, many research results have been obtained abroad, mainly related to the speed change law, variable speed limit control and real-time speed limit control in various areas of the operation area [4]. Domestic scholars mainly study the static speed limit problem and its evaluation of expressway maintenance area [5].

To sum up, there is a lack of research on speed distribution and speed limit at night in expressway maintenance area. Therefore, based on the measured speed detection data of one-way lane closed maintenance area of Anhui two-way four lane expressway, this paper determines the speed distribution law of each section of one-way lane closed construction of day and night expressway, and gives a
reasonable speed limit value. At the same time, this paper uses the factors that affect the capacity of expressway maintenance area to modify the speed limit value.

2. Field investigation of test section

In order to study the law of speed distribution at night in each area of expressway maintenance work area, the field traffic investigation of pavement maintenance of Shanghai-Shanxi Expressway (G40) was carried out. The expressway maintenance area is located in K120-122 section of Shanghai Shaanxi Expressway. The traffic volume and vehicle type data of the test section are collected by the automatic traffic volume survey instrument, and the survey location is the upstream warning area, transition area and work area. The location of the investigation is shown in Figure 1. At the same time, in the maintenance area where there are relatively few vehicles at night, from 22:00 to 24:00, the driving speed of HDV and LDV are recorded by driving recorder, and the recognition distance and perceived speed of different vehicles at night are analyzed.

![Figure 1](investigation_site.png)

Figure 1. Investigation site for closed maintenance operation area of highway single-lane road

Combined with the technical standard for Highway Engineering (JTG B01-2014) and the vehicle type division method of the automatic traffic volume survey instrument, motorcycle and minibus belong to LDV; other vehicles are HDV. MATLAB is used to process the night speed of the investigation points in each traffic control area of the investigation section, and the analysis results are shown in Table 1.

| Traffic control area | Vehicle type | Sample size | V15  | V50  | V85  | Vmin | Vmax  | Average | Standard deviation |
|---------------------|--------------|-------------|------|------|------|------|-------|---------|-------------------|
| warning area        | HDV          | 865         | 28.6 | 74.1 | 91.3 | 10.6 | 145.4 | 75.6    | 32.9              |
|                     | LDV          | 2136        | 34.1 | 75.0 | 95.1 | 10.8 | 148.6 | 79.7    | 34.6              |
| Transition area     | HDV          | 538         | 15.7 | 49.6 | 82.7 | 9.0  | 112.7 | 52.3    | 29.4              |
|                     | LDV          | 2496        | 18.3 | 47.2 | 83.9 | 9.0  | 130.1 | 53.1    | 28.1              |
| Work area           | HDV          | 476         | 54.6 | 66.4 | 77.1 | 25.5 | 85.2  | 66.1    | 10.58             |
|                     | LDV          | 2378        | 52.6 | 64.6 | 78.6 | 15.8 | 102.6 | 65.3    | 11.24             |

In order to show the short-term fluctuation of traffic flow, this paper sets the time interval as 5min to calculate the average value, the 15th% speed, the 50th% speed, the 85% speed and the standard deviation of vehicle speed of each group of samples.

3. Speed distribution law of each area in the night maintenance operation area

This paper takes the speed as the horizontal axis and the probability density as the vertical axis to fit the speed distribution at night, and draws the speed probability density curve of warning area, transition area, small and large vehicles in the maintenance area, as shown in Figure 2.
It can be seen from Table 2 that when the vehicles pass through the warning area, upstream transition area and work area in turn, the 85% speed of small vehicles gradually decreases, and small vehicles are speeding in each area. The 85% speed of large vehicles also shows a downward trend, and HDV are also exceeding the speed limit in each area.

Table 2. Traffic control area running speed statistic

| Vehicle type | Traffic control area | Warning area | Upstream transition | Work area |
|--------------|---------------------|--------------|---------------------|----------|
| LDV          | 91.3                | 82.7         | 77.1                |
| HDV          | 95.1                | 82.9         | 78.6                |

4. Research on recognition distance and perceived speed of maintenance area based on speed distribution law

4.1. Night recognition distance model of different models

According to the speed distribution law in the maintenance area, the night recognition distance of different vehicle models at different speeds is obtained through experiments, as shown in Table 3. According to Table 3, the maximum recognition distance of HDV and LDV is 305m and 251m, and the minimum values are 243m and 188m. And the recognition distance of large vehicle is far from that of small vehicle. The recognition distance of night maintenance work area decreases with the increase of vehicle speed.

Table 3. Night recognition distance of different vehicle types

| Vehicle type | Night speed (km/h) |
|--------------|--------------------|
|              | 40  | 50  | 60  | 70  | 80  | 90  | 100 |
| HDV          | 183 | 175 | 167 | 158 | 146 | 134 | 128 |
| LDV          | 181 | 173 | 162 | 148 | 140 | 130 | 120 |

Through the fitting analysis of the test data, the change rule of night recognition distance and speed of different models is shown in Figure 4. According to Figure 3, with the increase of vehicle speed, the recognition distance at night decreases gradually, and the recognition distance is gradually in the middle. By linear regression analysis of recognition distance with MATLAB software, the function relationship and correlation coefficient R of different vehicle types are 0.9939 and 0.9908 respectively. The expression of night recognition distance model of different models is as follows:

\[ D(v) = -0.9571v + 222.9 \]  \hspace{1cm} (1)

\[ d(v) = -1.039v + 223.3 \]  \hspace{1cm} (2)

Where: \( D(v) \) is the night recognition distance of HDV; \( d(v) \) is the night recognition distance of LDV.
4.2. Night sensing speed model of different models

The paper analyzes the perceptual speeds of different models at different vehicle speeds at night, as shown in Table 4. It can be concluded from Table 4 that when the speed of HDV and LDV in the maintenance operation area is greater than 80km/h, the night-time perceived speed of different models is basically the same as the vehicle speed. According to figure 4, perceived speed is directly proportional to the actual speed. Regression analysis with MATLAB software shows that the correlation coefficients R of different models are 0.9871 and 0.9837, respectively. The results show that perceived speed is significantly related to the actual speed. The expression of night perceived speed model of different models is as follows:

\[ F(v) = 1.161v - 15.54 \]  
(3)

\[ f(v) = 1.232v - 21.96 \]  
(4)

Where: \( F(v) \) is the night perception speed of HDV; \( f(v) \) is the night perception speed of LDV.

Table 4. Night perception speed of different vehicle types

| Vehicle type | Actual speed at night (km/h) |
|-------------|-----------------------------|
|             | 40  | 50  | 60  | 70  | 80  | 90  | 100 |
| HDV         | 35  | 40  | 50  | 65  | 80  | 90  | 100 |
| LDV         | 30  | 40  | 45  | 65  | 80  | 90  | 100 |

5. Study on speed limit at night in maintenance area

5.1. Speed limit model at night

In order to ensure safe driving, the vehicle identification distance must be greater than or equal to the stopping sight distance:

\[ S_D \geq S_t + S_0 \]  
(5)
Where: $S_D$ is the identification distance; $S_t$ is the stopping sight distance; $S_0$ is the safety distance ($S_0 = 3m$).

Stopping sight distance:

$$S_t = \frac{v}{3.6} T + \frac{v}{7.2} t + \frac{v^2}{25.92a_{\text{max}}}. \quad (6)$$

Where: $T$ is the braking reaction time ($T = 2.5s$); $t$ is the braking force rise time ($t = 0.2s$), $a_{\text{max}}$ is the maximum braking deceleration ($a_{\text{max}} = g(\varphi + i)$); $\varphi$ is the road adhesion coefficient; $i$ is the longitudinal slope.

Substituting formula (1), (2) into formula (5), the night speed limit models of large vehicles (7) and small vehicles (8) can be obtained:

$$v_D = [-0.84 + \sqrt{0.7 + 8.48/g(\varphi + i)}] \times 25.92 g(\varphi + i) \quad (7)$$

$$v_d = [-0.88 + \sqrt{0.77 + 8.49/g(\varphi + i)}] \times 25.92 g(\varphi + i) \quad (8)$$

Where: $v_D, v_d$ are the maximum speed limit values at night in the maintenance area of HDV and LDV.

5.2. Night speed limit correction based on perceived speed

In conclusion, due to the influence of speed, road adhesion coefficient, gradient, etc., vehicle speed perception will be deviated during driving, so the speed limit value will be corrected. According to formulas (3) and (4), the large and small vehicle speed deviations (9) and (10) can be obtained as follows:

$$\Delta v_D = v_D - (1.16v - 15.54) \quad (9)$$

$$\Delta v_d = v_d - (1.232v - 21.96) \quad (10)$$

Where: $\Delta v_D, \Delta v_d$ is the speed deviation of HDV and LDV.

Taking the speed deviation as the correction value of the night maintenance operation area, the maximum speed limit value of the night operation area after correction can be obtained, namely:

$$v_{mD} = v_D + \Delta v_D \quad (11)$$

$$v_{md} = v_d + \Delta v_d \quad (12)$$

Where: $v_{mD}, v_{md}$ is the maximum speed limit correction value of HDV and LDV in the maintenance area.

6. Case analysis

In this paper, the longitudinal slope is set to 0, different pavement adhesion coefficient is selected, and MATLAB software is used to solve the model, as shown in Table 6 (the result is an integer of 5). It can be seen from Table 5 that: under the same model, the speed limit value decreases with the decrease of the adhesion coefficient; when the adhesion coefficient is the same, the speed limit value of LDV is less than that of HDV, which may be caused by the distance between HDV and LDV at night. In addition, the calculated maximum speed limit is 95km/h (mainly due to the small traffic flow in the maintenance operation area), which is consistent with the distribution of the maximum running speed of vehicles at 100km/h. Therefore, the speed limit model is basically consistent with the actual traffic conditions.
Table 5. Calculation of speed limit at night maintenance work area

| Vehicle type | 0.6 | 0.5 | 0.4 | 0.25 | 0.15 |
|--------------|-----|-----|-----|------|------|
| HDV          | 95  | 90  | 85  | 75   | 65   |
| LDV          | 90  | 85  | 80  | 70   | 60   |

7. Conclusions
The night speed limit model of the working area is established by the night recognition distance and the perceived speed model. The maximum speed limit value of the work area is 95km/h and the minimum speed limit value is 60km/h, which is basically the same as the speed distribution of the vehicle in the maintenance area. Based on the analysis of measured data, this paper determines the distribution law of vehicle speed in night maintenance operation area and gives the method of speed limit value and correction.

Acknowledgments
The project relies on the technology project of Anhui Transportation holding Group Co., Ltd. (Project No:GSKY-2019-01).

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