Study on traffic flow characteristics of multi-lane freeway tunnel

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Abstract. The characteristics of traffic flow are recognized by studying the traffic flow variation law of multi-lane tunnel, which provides theoretical support for the management and control of multi-vehicle tunnel on expressway. By collecting traffic flow data of typical multi-lane tunnel, the relationship among running speed, traffic volume and mixing rate of large vehicles is analyzed. It is found that the inner lane has the highest speed, and the outward lane decreases successively. The higher the speed, the greater the speed difference between vehicles; The lower the mixing rate of large vehicles, the greater the velocity difference between vehicles; There is a negative correlation between the speed and the mixing rate of large vehicles. Finally, combined with the traffic volume and the mixing rate of large vehicles, the speed control strategy for different lanes is proposed.

1. Introduction

Under certain road conditions, speed is affected by the volume of traffic and the composition of traffic, and speed is an important factor affecting efficiency and safety. In the multi-lane long tunnel environment, the traffic condition is more complicated. Depressed and closed Spaces have a certain impact on drivers. Vehicles in different lanes have different running characteristics, which are mainly reflected in the aspects of running speed, traffic composition and volume.

With the construction of cross-river and cross-sea passageways, there are more and more multi-lane long tunnels, and the proportion of freight cars is relatively high. The research on speed control of long tunnel sections mostly stays in the simulation stage [1]. Research on traffic flow characteristics based on measured data is mostly focused on general road sections [2][3], which cannot reflect the impact of tunnel on drivers. Most of the research focuses on the analysis of section level [4], and mainly focuses on the study of traffic efficiency, but does not specifically analyze the operating speed. The number of accidents is significantly related to the speed difference, and the speed is closely related to the severity of accidents [5]. The mixing rate of large vehicles has obvious influence on the safety and efficiency of traffic operation.

By studying the relationship between running speed and characteristics, this paper summarizes the running speed characteristics of extra-long tunnel. And further put forward the speed control strategy under different traffic characteristics.
2. Methodology

Data were collected from 6 expressway tunnels in Guangdong Province. The design speed of the tunnel is 100km/h, there are 3 lanes, and the length of the tunnel is more than 3km. The acquisition location is located in the middle section of the tunnel, the longitudinal slope is less than 1.5%, and the geometric line is a straight section.

Select 9 sections to record section traffic information and continuously measure for 24 hours. The collection device is Vehicle Classifier System, which can collect lane position, speed, vehicle type, headway, time interval, axle number, axle group number and wheelbase.

For the passenger car lane, this study analysis the relationship between traffic volume and vehicle speed.

For mixed lanes, the mixing rate of large vehicles was used to characterize the traffic composition characteristics. Bootstrap was used to compare the differences between groups to determine the optimal number of clustering. Taking the mixing rate of large vehicles and V85 as the sample characteristics, the K-means clustering method was used to cluster the data samples, and the relationship models between the mixing rate of V85 and large vehicles in each traffic volume interval were established respectively. This study analysed the relationship between traffic volume and speed for large vehicle lane.

3. Result

3.1 Car lane

When the traffic volume of a single lane is below 735pcu/h, the V/C is less than 0.35, the service level is level one, the traffic flow is in the free flow state. As shown in Figure 1, the volume of traffic increases with the increase of speed.

![Figure 1. Car lane V85 and traffic volume diagram.](image)

At the first level of service, the efficiency of the lane depends on the speed of the vehicle itself. As the performance of small cars is relatively good, basically not affected by the longitudinal slope of the road. The speed limit of the small car lane is 100km/h.

3.2 Bus/Truck lane

As shown in Figure 2, the middle lane has a higher speed. The v85 of the outer lane is between 65km/h and 95km/h, and the v85 of the inner lane is between 55km/h and 90km/h. The smaller the traffic volume, the greater the speed dispersion.

In order to maintain the balance of traffic flow speed, this study calculated the speed control scheme under different traffic volume according to the speed flow curve.
Table 1. Outer lane speed control plan.

| Traffic volume (pcu/h) | Minimum speed (km/h) | Maximum speed (km/h) | speed control plan (km/h) |
|------------------------|----------------------|----------------------|--------------------------|
| 0–200                  | 55                   | 90                   | 70–90                    |
| 200–400                | 57                   | 88                   | 70–90                    |
| 400–600                | 60                   | 85                   | 70–90                    |
| 600–800                | 64                   | 81                   | 60–80                    |
| 800–968                | 73                   | 73                   | 60–70                    |
| 0–200                  | 55                   | 90                   | 70–90                    |

Table 2. Middle lane speed control plan.

| Traffic volume (pcu/h) | Minimum speed (km/h) | Maximum speed (km/h) | speed control plan (km/h) |
|------------------------|----------------------|----------------------|--------------------------|
| 200                    | 66                   | 95                   | 80–100                   |
| 400                    | 68                   | 94                   | 80–100                   |
| 600                    | 69                   | 92                   | 80–100                   |
| 800                    | 71                   | 90                   | 70–90                    |
| 1000                   | 73                   | 88                   | 70–90                    |
| 1200                   | 77                   | 84                   | 70–90                    |

3.3 Mixed lane
As shown in the Figure 3, the speed of vehicles in mixed lanes is affected by the mixing rate of large vehicles. The higher the mixing rate, the lower the speed. In the case of a higher mixing rate, the dispersion of the data is smaller.

Figure 3. The relationship between speed and large vehicle mixing rate.

Figure 4. Bootstrap sampling analysis

Bootstrap is used to determine the number of clusters. The optimal number of clusters is the number of clusters that makes Gap the smallest within a standard deviation. The sample comparison result is shown in the Figure 4, the Gap value is the smallest when the classification number is 7. The Gap value is the smallest when the classification number is 7.

Using the K-means clustering method, the mixed lane data is divided into 7 categories, and the clustering results are shown in Figure 5. The 7 sets of data have obvious differences in the distribution of traffic volume; Loess regression fitting is performed on the 7 sets of data to obtain the relationship between v85 and the mixing rate of large vehicles under different traffic volume conditions, as shown in Figure 6. As the mixing rate of large vehicles decreases, the operating speed gradually increases.
Figure 5. Traffic distribution

Figure 6. The relationship model between v85 and the mixing rate of large vehicles

According to the coverage of the traffic volume, the relationship model is used to predict the speed value under different mixing rates, and the prediction results are shown in Table 3.

| mixing rate of large vehicles | 0~0.1 | 0.1~0.2 | 0.2~0.3 | 0.3~0.4 | 0.4~0.5 | 0.5~0.6 | 0.6~0.7 | 0.7~0.8 | 0.8~0.9 |
|------------------------------|-------|---------|---------|---------|---------|---------|---------|---------|---------|
| traffic volume (pcu / h)     |       |         |         |         |         |         |         |         |         |
| 0~59                         | 102~112|         |         |         |         |         |         |         |         |
| 59~224                       | 98~102 |         |         |         |         |         |         |         |         |
| 224~383                      | 99~99  | 99~97   |         |         |         |         |         |         |         |
| 383~492                      | 98~99  | 99~99   | 99~99   |         |         |         |         |         |         |
| 492~617                      | 96~99  | 98~99   | 98~99   | 99~99   |         |         |         |         |         |
| 617~797                      | 94~95  | 93~98   | 85~88   | 81~85   | 83~90   |         |         |         |         |
| 797~1250                     | 90~94  | 85~93   | 83~86   | 81~85   | 83~90   | 80~82   | 80~82   |         |         |
According to the speed prediction results, combined with the goals of improving speed consistency and reducing speed difference, formulate a speed control plan, as shown in Table 4.

Table 4. Speed control scheme of mixed lane under different traffic volume (km/h)

| mixing rate of large vehicles | traffic volume (pcu/h) | 0–50 | 50–200 | 200–400 | 400–500 | 500–600 | 600–800 | 800–1250 |
|------------------------------|------------------------|------|--------|---------|---------|---------|---------|----------|
| 0.0–0.1                     |                        |      |        |         |         |         |         |          |
| 0.1–0.2                     |                        |      |        |         |         |         |         |          |
| 0.2–0.3                     | 90–100                 |      |        |         |         |         |         |          |
| 0.3–0.4                     | 90–100                 |      |        |         |         |         |         |          |
| 0.4–0.5                     | 90–100                 |      |        |         |         |         |         |          |
| 0.5–0.6                     | 90–100                 |      |        |         |         |         |         |          |
| 0.6–0.7                     | 80–100                 |      |        |         |         |         |         |          |
| 0.7–0.8                     | 80–100                 |      |        |         |         |         |         |          |
| 0.8–0.9                     | 80–100                 |      |        |         |         |         |         |          |

4. Conclusion
For car lanes, at the first level of service, the speed is positively correlated with the increase in traffic volume.

For bus/truck lane lanes, the smaller the traffic volume, the greater the dispersion of speed. When the speed of the middle lane is 81km/h, the traffic volume reaches the maximum value of 1250 pcu/h, and when the speed of the outer lane is 72km/h, the traffic volume reaches the maximum value of 880 pcu/h; the overall speed of the middle lane is higher than that of the outer lane.

For mixed lanes, under different traffic volume intervals, the relationship between the mixing rate and speed of large vehicles is different; the higher the mixing rate of large vehicles, the lower the speed; the lower the mixing rate, the greater the discrete type of speed.

Finally, speed control strategies for different types of lanes are proposed, which effectively improves the operational safety and traffic efficiency of multi-lane highway tunnels.

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References
[1] LIANG Guo-hua. Relationship between mixing rate of freeway large vehicles and traffic flow stability[J]. Journal of Chang’an University: Natural Science, 2014(34):120-126.
[2] DUAN Li. Characteristics of traffic flow on 8-lane freeway under lane restriction strategy[J]. Journal of Highway and Transportation Research and Development, 2014, 031(004):125-129.
[3] CHEN Zhao-liang. Operating safety characteristics of six-lane expressways under the speed limit strategy of lanes[J]. Journal of Highway and Transportation Research and Development: Application Technology, 2016(12):175-176.
[4] WEN Xue-jun. Study on Expressway Operation Speed[J]. Journal of Highway and Transportation Research and Development, 2002(2):80-82.
[5] TANG Cheng-cheng. Speed Limit and Safety [J]. Journal of Highway and Transportation Research and Development, 2005(3):97-100.