Calibration of the Gipps’ Car-following Model Using High Altitude Video Data

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ABSTRACT

In order to calibrate the car-following model accurately, this paper studied single group of vehicles and multi groups of vehicles separately by using comparative analysis method. The high-altitude video capture method was used to capture the vehicle travel trajectory on a certain length of urban road. Subsequently, the coordinate system was established by the ground markers to collect the data that the Gipps’ model needed, such as position, speed and acceleration of every two consequent cars. After that, 6 sets of single car-following data and 1 set of multi car-following data were used to calibrate parameters by non-linear regression method. Then, the difference of some single groups are smaller than multiple group (5%) through comparing predicted values with actual measured space headway, while the errors in part of those single groups are significantly larger than those in group 7, with values of more than 1.519, 2.818 and 2.332 times respectively. This study proves that multiple groups of vehicles’ data can avoid the errors form some single group of vehicles when calibrate Gipps’ car-following model. Finally, through the sensitivity analysis of traffic volume, this research found that the maximum single lane traffic volume on the Xi’erhuan road in Xi’an is 1415 veh/h/line. The results show that it is simple and easy to address this question by the high-altitude video capture method, and the multi groups of vehicles could do better in the car-flowing model calibration.

KEYWORDS: Transportation Engineering, Traffic investigation, Gipps’ car-following model, High Altitude Video Data

1 INTRODUCTION

Micro traffic flow theory is such a theory and method aiming at analyzing and modelling traffic behavior characteristics of individual vehicles, which reveals the influence among different individual operating vehicles and is crucial to road transport relevant researches. The car-following model based on safety distance is mainly based on the assumption that the driver expects to keep safety distance headway between the lead vehicles. Many famous traffic simulation softwares have adopted similar safe distance model as their core model (Ma et al, 2016). Gipps (1981) considered the constraints of vehicle acceleration and safety distance, and then proposed the Gipps’ car-following model. The parameter calibration of Gipps’ car-following model generally requires data about the speeds and
positions of leading vehicle, the speeds of following vehicle and the positions of following vehicle for every second.

Brackstone (2002) and Vasconcelos (2014) used on-board instruments, sensors and other devices to collect data, which indicates the vehicle following characteristics of drivers. However, these kinds of methods fail to reveal the differences between individuals and cannot reflect car-following characteristic of whole road because of too many driving vehicles in the whole section. Jing and other researchers (2015) collected car following information about 25 drivers using on-board devices, and found that the cost of investigation is too expensive to carry out actual implementation. Ranjitkar (2005) used GPS data to research vehicle trajectory data acquisition, also found the diverse between individual drivers. But the drivers are required during the former process of data collection and latter of that, only college school students between 22 and 30 years old are chosen as car following drivers. This method filtered and informed those drivers in advance before the experiment carried out, the data collected also rested on theoretical level and was difficult to analysis the actual situation. Ossen (2005) used helicopter shooting method, which can acquire video data of section preferably, however, the expensive cost during data acquisition process lead to not applicable widely research.

This article divided data collection of car following behavior into the method of high altitude video acquisition and car following with instrument. High altitude video acquisition involves risks of huge deviations when use GPS technology, also costs highly when collect data and is limited by collection sites, which is not suitable for wide application. If car following method with devices are applied, it is difficult to represent the following behaviors of the whole road with fewer drivers, on the contrary, the cost of data acquisition is high with more drivers. In addition, this method will inform and filter drivers who cannot represent the operating characteristics of the whole road in advance. Therefore, the project adopts the method of shooting video by UAV, both reduces the cost of video acquisition and detects the car following behavior of multiple groups simultaneously when the detected people are unaware. Calibrating parameters of Gipps car-following model by data of single and multiple groups car following behaviors, thus demonstrate the advantages and disadvantages of one and multiple groups data calibration model.

The structure of the article is as follows. The second chapter reviewed Gipps car-following model. The third section established the relationship between car-following model and macro traffic flow. The fourth section detailed claimed the process of data acquisition and reveal the results of data collection. In last chapter, the data were analyzed. Firstly, the parameters of Gipps car following model were calibrated by single group and multiple groups’ data. Then built deviation evaluation index SS by comparing data collected. Compared the discrepancy of predicted model results based on single group data and multiple group data, found that model calibration with multiple sets of data could reduce the error of single set of data parameters. Finally, adopted multiple groups’ data calibration to research the results of different driving speeds conditions, as well as traffic volumes under the steady conditions. And required the maximum traffic volume corresponding to density and speed through sensitivity analysis of the driving speeds.

2 GIPPS’ CAR-FOLLOWING MODEL

Gipps (1981) established the following model, where the first equation is a free-flow model and the second equation is a model in non-free-flow state, as shown in equation (1).

$$v_n(t + \tau) = \min \left\{ \begin{array}{l}
v_n(t) + 2.5\alpha_n \tau\left(1 - \frac{v_n(t)}{V_n}\right) \sqrt{0.025 + \frac{v_n(t)}{V_n}} \\
-b_n \left(\frac{\lambda}{2} + \theta\right) + \sqrt{b_n^2 \left(\frac{\lambda}{2} + \theta\right)^2 + b_n^2 \left(2\left[x_{n-1}(t) - x_n(t) - S_{n-1}\right] - \tau v_n(t) + \frac{v_{n-1}^2(t)}{b_{n-1}}\right)} \end{array} \right. \quad (1)$$
where \( x_{n-1}(t) \) and \( x_n(t) \) are, respectively, the longitudinal positions of vehicles \( n-1 \) (leader) and \( n \) (follower) at time \( t \), similarly, \( v_{n-1}(t) \) and \( v_n(t) \) are respectively the leader’s and follower’s speeds at time \( t \). \( v_n(t + \tau) \) means the follower’s speed at time \( t + \tau \), \( \tau \) is the reaction time, \( a_n \) and \( V_n \) are respectively the follower’s maximum acceleration and desired speed, \( b_n \) and \( b_{n-1} \) are respectively the leader’s and follower’s maximum deceleration, \( \theta \) is additional reaction time in order to ensure safety, \( S_{n-1} \) is the “leader’s effective length”, that equals, the leader’s real length added to the follower’s desired inter-vehicle spacing at stop \( S_{n-1} \).

![Figure 1. The Basic Scene of Car-following Model](image1)

There are \( N \) cars in Figure 1. Their numbers are 1, 2, 3, ..., \( n-1 \), \( n \), \( n+1 \), ..., \( N \) from front to back. Vehicle \( n \) follows the vehicle \( n-1 \), and Vehicle \( n+1 \) follows the vehicle \( n \).

![Figure 2. The Plot of Gipps’ Car-following Model](image2)

Figure 2 shows the principle of calculating the minimum safe distance. The leader vehicle \( n-1 \) starts to break urgently at time \( t_2 \). It completely stopped at time \( t_2 \). Finally, the follower vehicle \( n \) stopped at time \( t_3 \). When the two cars are completely stopped, there is a spacing \( d \) that drivers are unwilling to invade. Thus, the “leader’s effective length” \( S_{n-1} \) equals the leader’s real length plus \( d \). In this study, \( S_{n-1} \) is 5 meters.

### 3 TRAFFIC VOLUME ANALYSIS BASED ON CAR-FOLLOWING MODEL

The Gipps’ model describes the relationship between leader and follower. It expresses microscopic phenomena, and then, macro features of traffic also explained. The leader’s speed is prospective hypothesis. The change-in-speed could be considered as linear with a minimal time interval \( \Delta t \). Thus, the leader’s acceleration is expressed by equation (2).

\[
a_{n-1}(t) = \frac{v_{n-1}(t + \Delta t) - v_{n-1}(t)}{\Delta t}
\]  
(2)
According to Newtonian Kinetic formula, the leader’s position is given by expression (3).

\[ S_{n-1}(t + \tau) = S_{n-1}(t) + \frac{v_{n-1}^2(t + \tau) - v_{n-1}^2(t)}{2 \times a_{n-1}(t)} \] (3)

The follower’s speed calculated by Gipps car-following model. The follower’s speed at time \( t + \tau \) is given by the minimum of the expression (1) above.

\[ v_n(t + \tau) = \min \left\{ v_n^{acc}(t + \tau), v_n^{dec}(t + \tau) \right\} \] (4)

Then, the follower’s acceleration and position are respectively given by equation (5) and (6).

\[ a_n(t) = \frac{v_n(t + \Delta t) - v_n(t)}{\Delta t} \] (5)

\[ S_n(t + \tau) = S_n(t) + \frac{v_n^2(t + \tau) - v_n^2(t)}{2 \times a_n(t)} \] (6)

With the leader’s position minus the follower’s position, the space headway is given by equation (7).

\[ h_d(t) = S_{n-1}(t) - S_n(t) \] (7)

The space headway affects the road traffic density and further affects the traffic volume. Traffic density refers to the number of vehicles on a unit road length at a given time. Thus, the relationship between density and average space headway is given by expression (8).

\[ k = \frac{1000}{h_d} \] (8)

where \( k \) is traffic density, its unit is \( \text{veh} / \text{km} / \text{ln} \), \( h_d \) is average space headway, its unit is \( m \).

According to the relationship between three parameters of traffic flow, the relationship between density, space headway and volume is expressed by equation (9).

\[ q = v \times k = 1000 \times \frac{v}{h_d} \] (9)

The space headway is variable in different speed of the stable traffic stream. By changing the leader’s speed, the sensitivity analysis of traffic volume is finished by Gipps car-following model (1) and equation (9), then found the maximum traffic volume \( q_{max} \) and the corresponding density \( k_m \) and speed \( v_m \).

4 DATA COLLECTION

To study the following model real data was collected using a pair of instrumented vehicles equipped with datalogger devices, including the position, velocity and acceleration difference of the neighboring two cars. However, this method can’t describe the car-following behavior accurately because of the limited sample size of drivers.

In this paper, high-altitude video capture method is used to record the video, and the video is processed by Simi motion. In this way, data can be collected easily and comprehensively, bias caused by limited sample size of drivers eliminated and car-following behavior described much better.

We collected data by “Da Jiang Elf 4” UAV (height of 120 meters and length of 150 meters) on a section of Xi’erhuan Road in Xi’an during a Wednesday evening rush hour, the section located in the middle of the viaduct, which avoided the lane-change behavior and the error caused by the elevation difference between the two ends of the viaduct.

The time-step in UAV video and the time interval that Simi Motion captured the car-following data are all 1/24 second. Then, the model variables (position, speed and acceleration) of leader’s and follower’s is obtained.
As shown in Figure 3, Simi Motion can capture the moving objects’ information of movement. In order to capture the data set accurately, the same place of leader and follower could be selected as data collecting sites. Then 7 sets of car-following data is captured using the same method, where 6 sets of data used to calibrate Gipps’ model, while one set of data was used to test the calibrated models. The 6 sets of captured data used to calibrate Gipps’ model are shown below with 1/24 second time-step.

The plots in Figure 4 display the 6 sets of car-following data respectively. The thinner lines are leader’s and thicker lines are follower’s. In graph a) and f), when the leaders change speed, the followers show the similar trend with a high fluctuation. In graph b), c), d) and e), the lagging between two cars is well showed. The follower follows the leader’s speed changes. The X-axis is time-step, and the Y-axis is speed. So the areas between the thinner line and thicker line is distance in the longitudinal positions. When the thinner line over the thicker one, the leader’s distance longer than follower’s. Sometimes the thinner line over the thicker one while sometimes the thicker line over the thinner one, thus, the space headway between two cars is a fixed value in the long time.
5 DATA COLLECTION

5.1 Parameters calibration

According to Rakha’s method (2007), combined with the physical meaning of parameters and considered the real environment of data collection, the range of Gipps car-following model parameters are given as follows: $a_n = 1 \sim 4 \text{m/sec}^2$, $b_n = -4.0 \sim -1.0 \text{m/sec}^2$, $b_{n-1} = -4.5 \sim -1.0 \text{m/sec}^2$. Additionally, $V_a$ is calculated by the cars’ running performance in this specific situation.
Table 1. Parameters Calibration Results

<table>
<thead>
<tr>
<th></th>
<th>$b_{n-1}$</th>
<th>$b_n$</th>
<th>$R^2$</th>
<th>$a_n$</th>
<th>$V_n$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.753</td>
<td>1.231</td>
<td>0.541</td>
<td>1.395</td>
<td>7.489</td>
<td>0.796</td>
</tr>
<tr>
<td>2</td>
<td>3.161</td>
<td>1.309</td>
<td>0.545</td>
<td>1.542</td>
<td>5.766</td>
<td>0.943</td>
</tr>
<tr>
<td>3</td>
<td>2.394</td>
<td>2.247</td>
<td>0.696</td>
<td>1.528</td>
<td>7.724</td>
<td>0.902</td>
</tr>
<tr>
<td>4</td>
<td>2.148</td>
<td>2.088</td>
<td>0.652</td>
<td>0.699</td>
<td>7.100</td>
<td>0.705</td>
</tr>
<tr>
<td>5</td>
<td>1.325</td>
<td>1.478</td>
<td>0.328</td>
<td>1.192</td>
<td>6.107</td>
<td>0.386</td>
</tr>
<tr>
<td>6</td>
<td>2.163</td>
<td>1.215</td>
<td>0.502</td>
<td>1.867</td>
<td>8.760</td>
<td>0.399</td>
</tr>
<tr>
<td>7</td>
<td>2.175</td>
<td>2.096</td>
<td>0.541</td>
<td>1.254</td>
<td>9.205</td>
<td>0.796</td>
</tr>
</tbody>
</table>

The 6 sets of captured data were used to calibrate Gipps car-following model respectively. Then all of the 6 sets of data were considered as group 7. The calibration results are in the recommended range except the leader’s acceleration of group 4. In general, the calibration results can be regarded as relatively accurate.

5.2 Calibrated model test

The test data set captured by Simi Motion is shown in Figure 5.

![Figure 5. Measured Speed of Leader’s and Follower’s](image)

In the test data set, the variable speed of two cars have obvious features of car-following situation. So it can be considered as standard data to test the 7 calibrated models. Inputting the leader’s position, speed and acceleration, the follower’s position and their space headway were predicted.
In Figure 6, the thicker lines were measured space headway while the thinner lines are Gipps’ predicted values of 7 groups. All of the Gipps’ predicted values have the similar tread with the measured data. The thinner line in graph b) is Gipps-7. Including all 6 sets of data, it is similar with the measured values. In graph c), space headway in Gipps-3, Gipps-4, Gipps-5 are also similar with measured data. However, the other groups’ predicted values have a greater gap with the measured space headway in graph d). Further, the difference between the measured and Gipps’ can accurately represent as SS (Sum of Squares).

$$SS = \sum (x_i' - x_i)^2$$  \hspace{1cm} (10)

where $x_i'$ is the measured space headway value at time $i$, $x_i'$ is Gipps’ predicted value at time $i$.

Finally, the values of SS is shown in Table 2.

<table>
<thead>
<tr>
<th>Group</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS</td>
<td>7901.05</td>
<td>11975.95</td>
<td>2987.44</td>
<td>3113.72</td>
<td>3256.08</td>
<td>10450.95</td>
<td>3136.38</td>
</tr>
<tr>
<td>Rate</td>
<td>2.519</td>
<td>3.818</td>
<td>0.952</td>
<td>0.992</td>
<td>1.038</td>
<td>3.332</td>
<td>1</td>
</tr>
<tr>
<td>Bias</td>
<td>1.519</td>
<td>2.818</td>
<td>-0.047</td>
<td>-0.007</td>
<td>0.038</td>
<td>2.332</td>
<td>0</td>
</tr>
</tbody>
</table>

Taking the SS value of group 7 as the denominator In Table 2, rates of each group calculated in the third line. Then taking the rate of group 7 as the standard value, the bias’ value is given by the rates of every group minus 1. The difference of group 3, 4 is smaller than group 7, and it limited to 5%. However, the errors in groups 1, 2, 6 are respectively 1.519, 2.818 and 2.332 times larger than those in group 7. So, if the single set of data is used for parameter calibration, the results are
indeterminate. It might have a large difference with the real traffic conditions. The results show that using multiple sets of data to calibrate Gipps’ car-following model is better than the single set of data. It avoid the larger errors caused by the single set of data.

5.3 Sensitivity analysis of traffic volume

The inputting variables of leader’s (positions, speeds and acceleration) are prospective hypothesis. The follower’s variables predicted using group 7, the optimal calibrated Gipps’ car-following model. Then, the space headway and volume in various situations calculated respectively.

In the sensitivity analysis, time-step set as 1 second, total length is 100 time-steps, the leader’s acceleration is 0 that means the steady traffic stream, the leader’s original position is 5 meters in the longitudinal positions while the follower’s is 0, the leader’s speed set as 1km/h, 2km/h, 3km/h,…, 30km/h and the maximum speed 33.138km/h respectively in each experiment. In each experiment, the follower’s original speed lower than the leader’s, but it couldn’t affect the results. After 17 groups’ analysis, the results were shown in Table 3 and Figure 7.

![Figure 7. The Space Headway and Volume of Sensitivity Analysis](image)

**Table 3. Results of Volume Sensitivity Analysis**

<table>
<thead>
<tr>
<th>$v_{n-1}(t)$ km/h</th>
<th>$v_{n-1}(t)$ m/s</th>
<th>$h_d(t)$ m</th>
<th>Volume veh</th>
<th>$v_{n-1}(t)$ km/h</th>
<th>$v_{n-1}(t)$ m/s</th>
<th>$h_d(t)$ m</th>
<th>Volume veh</th>
</tr>
</thead>
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<td>190</td>
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<td>5.00</td>
<td>12.91</td>
<td>1394</td>
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<tr>
<td>2</td>
<td>0.56</td>
<td>5.56</td>
<td>360</td>
<td>19</td>
<td>5.28</td>
<td>13.54</td>
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<tr>
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<td>33.138</td>
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Though the sensitivity analysis, the maximum volume in Xi’erhuan Road is 1415 veh/h, and the corresponding optimal speed is 22km/h, where the best density is 64veh/km. Wangwei et al. (2011), considering the current situation of Chinese cities, drew the conclusions:
1. Under the speed of 20km/h, the theoretical capacity of one lane calculated by space headway is 1406 pcu/h.
2. Under the speed of 20km/h, the theoretical capacity is 1380 pcu/h according to Code for Design of Urban Road of China.
3. The theoretical capacity is 1348pcu/h calculated by time headway.

The result of sensitivity analysis is similar with this consequence. Thus, 1415veh/h could be considered as the actual capacity of Xi’erhuan Road.

6 CONCLUSION

(1) Through the study, UAV-high-altitude video method is an efficient and reliable data acquisition method for the car following model parameters calibration. This study used an unmanned aerial vehicle (UAV), selected a section with 150 meters length to carry out high-altitude video shooting assignment. We can use more UAVs at the same time for data acquisition. In this way, the longer road section can be captured by video; more exact model parameters calibrations will be acquired.

(2) This study compared model predicted values with measured values by experiments, in which the SS of single group data were 7901.05, 11975.95, 2987.449, 3113.723, 3256.088, 10450.95, while the SS of multiple group data was 3136.381. The results illustrate that the calibration results of multiple group data can avoid the errors caused by single group data, and express the stream status of the entire road accurately.

(3) By inputting different original variables, the sensitivity analysis of traffic volume proves that the maximum single lane traffic volume on Xi’erhuan road is 1415 veh/h/line, and the corresponding optimal speed is 22 km/h in this specific traffic stream, where the best density is 64 veh/km.

REFERENCES


