The establishment of a car-following model based on driver’s visual angle experiments

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Deduction may be wrong if we miss the part of human perception. In this paper we design a field experiment to measure the driver’s perceptual car width. That car is standing still in front of that driver inside a vehicle cab. We deduce our perceptual car following model based on the results above and also show its connection with the GM’s car following model. The model we present here is not very like the one based on the general driver’s perceptual model. Additionally we establish a car-following simulation model based on our findings. The simulation performances are interpreted in terms of car following stability, shock wave phenomena, and some macroscopic traffic parameters.

KEYWORDS: Perceptual Car-Following Model, Traffic Simulation

where,
- \( a_f \) is the acceleration rate of the follower,
- \( dv(t) \) is the differential velocity between leader and follower at time \( t \),
- \( dx(t) \) is the distant headway between leader and follower at time \( t \),
- \( \lambda_0 \) is the driver’s sensitivity parameter,
- \( t \) is the time,
- \( T \) is the driver’s reaction time.

2. General driver perceptual model
There are two existing car-following reasoning theories, one is based on the perceptual factors of drivers, and the other is the stimulus-response equation. We may relate the model based on drivers’ perception with the Greenshields model by

\[ \frac{d\theta}{dt} = \frac{W}{S} \frac{dS}{dt} \]  

(1)

If, \( a_f = c(\theta) \), and, \( S = X_{n+1} - X_n \), the equation above is identical to the following equation,

\[ \alpha_f(t + T) = \lambda_0 \cdot \frac{dv(t)}{(dx(t))^n} \]  

(2)
3. Experiment design for measuring driver’s perception

In order to measure the perceptual size of automobile from the viewpoint of the driver inside that car. We designed an instrument, a kind of special ruler, and set up a measuring procedure. The relationship between driver’s perceptual car size and the cars’ distant spacing is to be found following the measuring procedure. This result can be used to display more realistic simulated images if we are doing some experiments about drivers’ perceptions or their driving behaviors. Its configuration and the measuring method are described as follows. The experimental instrument is formed as a big ruler and is set up next to the front bumper of the driver’s car for measuring the perceived sizes of leading car seen by the driver inside the vehicle. It is illustrated in Figure 2.

![Figure 2 The Measuring Ruler for Driver’s Perception](image)

We can then utilize the above-mentioned device to measure the leading vehicle’s width perceived by the driver at different following distances. This can be illustrated in Figure 3.

![Figure 3 The Experiment for Searching the Relationship Between Leading Car’s Visual Width and Both Cars’ Spacing](image)

The driver’s perceptual size of his leading vehicle, i.e. vehicle width, at different distant spacing is then measured. The test drivers’ information and the physical geometry of the front target car are shown in Table 1.

<table>
<thead>
<tr>
<th>Physical Car size</th>
<th>Width (cm)</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Driver A</td>
<td>Driver B</td>
</tr>
<tr>
<td>Height of eyes to ground (cm)</td>
<td>114.5</td>
<td>112.2</td>
</tr>
<tr>
<td>Distance for eyes to front bumper (cm)</td>
<td>207</td>
<td>207</td>
</tr>
<tr>
<td>Driver’s height (cm)</td>
<td>177.5</td>
<td>157.5</td>
</tr>
</tbody>
</table>

![Table 1 The Physical Geometry of Test Car and Test Driver Information](image)

After field measurements, these data are fitted for several function forms, i.e. linear, log-linear, exponential, and exponential. These function forms then are tested by using nonlinear curve-fitting techniques. The best-fitted functions of two drivers’ experiments are listed as follows:

1. Visual Width = 110.09 x (Car Spacing)\(^{0.6843}\), \(R^2=0.9755\)
2. Visual Width = 111.68 x (Car Spacing)\(^{0.6878}\), \(R^2=0.9745\)

Because these two functions or drivers’ characteristics are close enough, we can combine them together. The following scatter plot and fitted function are obtained based on the average value from field experiments of test driver A and B.

![Figure 4 The Scatter Plot and Best-fitted Curve of the Driver’s Perception to Leading Car’s Width](image)

The best-fitted nonlinear equation of driver perceived width is \(Y = 110.86 \times X^{0.6843}\), where \(Y\) is the visual car width with different vehicle’ spacing, \(X\). The \(R^2\)-value is 0.9753. It shows that the goodness of fit of this function form is good enough. The result shows that the perceived equations derived from two drivers’ tests are quite alike despite of different test driver’s characteristics. Therefore, the combination of test data from two drivers will be reasonable for the final equation construction. We then use the equation of statically perceived vehicle width to infer the driver’s perception of front car by differential it with distance, \(X\). It indicates the following facts by using the same procedure shown above. The equation then becomes,

\[
\frac{dY}{dt} = 110.86 \times x^{0.6843} \frac{dx}{dt} = 110.86 \frac{dv(t)}{dx(t)^{0.6843}}
\]  \(1\)

where,

- \(dv(t)\), is the differential velocity between leader and follower,
- \(dx(t)\), is the spacing between leader and follower.

Equation (3) that deduced from those experimental data is slightly different from the one we knew before. The comparisons between Equation (3) and other studies of the car-following models are shown in Table 2.

The parameters, \(L\) and \(M\), of the nonlinear car-following model are 1.6843 and 0 respectively. We can realize that it is somewhat different from the findings in Table 2. Besides, according to the report of Michaels, R.M. (1963)\(^9\), the dri-
vers' perceptual threshold in an actual driving situation is reasonable to be the mean of 3-10x10^4 rad./sec, that is, 6x10^4 rad./sec. If we assume the distant spacing between cars is 20 meters and the speed difference between the two cars is 18 KPH, then the angular speed will be 6.22x10^4 rad./sec. Or if the distant spacing is 10 meters and the speed difference between the two cars is 3.6 KPH, then the angular speed will be 4x10^4 rad./sec. These deductions seem easy to be imagined for the actual driving condition but are hard to describe the driving situation for the leading car.

4. Driver's perceptual car-following model performance

A new car-following simulation model is built to examine the characteristics of the said model based on our experimental findings mentioned above. This car following model is equipped with a virtual car in an experimental highway world constructed by a virtual reality developing tool. In addition to the original simulation purpose, it can also be utilized to discover some latent factors existed in the driving behavior through its virtual reality effect.

4.1 Model Description

The key items of this simulation model are listed as follows:

1. Microscopic time scanning period: 10 frames per second.
   The performance of this dynamic graphical simulation model is fixed at 10 frames per second for the assurance of time progresses between the virtual world and the real world.

2. Driver's characteristics: the chance is three to two that will make driver to become a risk-oriented driver. This reaction time falls in the range of 0.5 sec to 1.5 sec, and desired speeds are also randomly selected from 70 KPH to 100 KPH; the possibility for becoming a conservative driver is 2/3. This reaction time then falls in the range of 1 to 2 sec, and desired speeds are from 40 KPH to 70 KPH. Besides, the estimated driver's sensitivity parameters are calculated according to the following equation:

\[
    C = \lambda_1 T = \frac{\lambda_2}{dx(t)_{max}} T
\]

where,

\( C \) is the stability factor, equals to 0.5, 1, and 1.57 separately, \( \lambda_2 \) and \( \lambda_1 \), are driver's sensitivity parameters.

3. Time Lag (Sec): Car 2  Car 13  Car 26  Car 14  Car 4  Car 11

4. Maximum Speed (KPH): 50.76  60.15  83.88  78.48  73.8  91.08

5. Driver's Sensitivity: 7.84E+12  306164  35742  35742  52992.6  61285.1

6. Car 5  Car 6  Car 7  Car 8  Car 9  Car 10

7. Time Lag (Sec): 0.5  1.5  2  1.4  1.2  1.3  0.7

8. Maximum Speed (KPH): 46.6  75.26  51.48  58.55  0.7  1.4  1.6

9. Driver's Sensitivity: 1.4343  1.7700  2.0412  3.6497  1.5  1.5  1.5

10. Car 21  Car 22  Car 19  Car 24  Car 23  Car 3

11. Time Lag (Sec): 7.76  15.64  18.2  95.4  94.68  67.22

12. Maximum Speed (KPH): 77.76  15.64  18.2  95.4  94.68  67.22


- T is the reaction time of driver,
- \( dx(t)_{max} \) is the distant spacing between two cars.

So every driver's sensitivity parameter is probably different if his reaction time is randomly generated.

3. Detector allocation: three sets of detectors are located in the virtual road environment. It can be taken as a loop-type detector. The traffic speed and flow can then be calculated from the collected data.

4. Car movement limitation: the maximum vehicle acceleration rate is 1.0668 m/s², and the maximum deceleration rate is 4.8768 m/s². If the driver's travel speed is higher than his desired speed, then this car will be forced to follow its desired speed rule.

5. Simulation concept: due to the computation capability limitation of current personal computer while applying to construct a real-time simulated world, there are only few cars existing on a road with 2 kilometers in length in the model at the same time. But each of the simulated cars detects its surrounding cars and executes the car-following rule mentioned in the previous section. When the simulated car drives to the end of the road segment, it will go back to the starting point of the road again. In this way, the simulation runs recursively until a special event happened and then to terminate it.

The output performance of the perceived car-following phenomena is checked in two steps. The first step is to generate 19 cars one by one randomly and all are driving on the one-kilometer road. The characteristic of this model is then checked in terms of the car-following asymptotic stability and the shock wave phenomena. Next, we try to extend the road length to two kilometers and put up to 40 cars into the simulation model for examining the differences of macroscopic traffic parameters between 40-car case and 20-car case that are running in the same road condition of the simulated world.

4.2 Simulation Results

The simulation results can be separated into two parts. In the first part, the results are interpreted in terms of car-following asymptotic stability and shock wave phenomena. The purpose is to check the suitability of the model. The second part shows the differences of macroscopic traffic parameters, K,
Q, V, for the cases of two different traffic conditions. In the first step, the results are shown as follows:
1. Driver's Information of the Following Car
The simulation results are shown in Table 3.

2. Car-following asymptotic stability
The traditional driver's perceptual car-following model is applied to this new car-following simulation model. The stability factor, C, equals separately to 0.5, 1, 1.57, which are used in three simulation tests. The leading car is set to speed up with its maximum acceleration rate in the first 60 seconds. Then it decelerates with half of the maximum deceleration rate for the next 30 seconds, and maintains its speed during the following 70 seconds. Then moves ahead with its maximum acceleration rate again and finally slow its speed down to zero with maximum deceleration rate. The numbers of car-following drivers are 6, 4, and 6 respectively for different stability factors, 0.5, 1.0, and 1.57. The characteristics of the followers are the same as the data described above. The speeds and the cars' spacing fluctuations can be seen in the following Fig. 5 to Fig. 7.

Figure 5 The Model Stability and Velocity Fluctuations for C=0.5

Figure 6 The Model Stability and Velocity Fluctuations for C=1.0

Figure 7 The Model Stability and Velocity Fluctuations for C=1.57
In the case of $C=0.5$, the serial drivers' car-spacing curve tends to be a kind of damped amplitude. In the case of $C=1.57$, it seems to be oscillatory with undamped amplitude. They are very similar to the results of Herman and Potts (1961).\(^8\)

3. Car movement trajectory and shock wave phenomena
In Figure 8 it can be found easily that the forms of shock waves belong to frontal stationary shock waves and backward forming shock waves. These phenomena can be seen also at urban signalized intersections.

4. Flow-Density-Velocity relationships
The K-Q-V relationships are established from data collected by the virtual vehicle detectors in said simulation experiments. From those diagrams of Speed-Density relationships for various parameters M, L combinations in the study of May
and Keller (1967)\textsuperscript{a}, we can find their forms of Speed-Density scatter plot are very like the case of M equals to 0, and L falls in between 1 and 2. Because of the variation of drivers' characteristics and speed limitation, the Flow-Density relationship are like the findings of Forbes, T.W. (1963)\textsuperscript{a}. As to the Speed-Flow relationship, the drivers' velocity seems to concentrate between 30 KPH and 70 KPH in the case of 20 cars. But the more cars driving on the road, the larger variation the parameters will be. It is implied that the more cars driving on a limited-length road, the more differences existed among driving behaviors of different drivers. It seems that drivers' feelings of danger will increase in this case.

5. Conclusion

In this study, we present another viewpoint for the car-following model; that is, the driver's perceptual size for the car driving ahead is not as large as its physical geometry. We have also established a new car-following simulation model based on our new research findings. In the simulation results, the car-following asymptotic stability, shock wave phenomena, and Q-K-V relationships are all shown to be quite reasonable so that this simulation model can be applied in our future studies. There are so many car-following models currently. Nobody can be sure that which one is most capable to picture the real car-following behaviors because each model has parts of supporting evidences. Maybe the varieties of drivers cause those variations among all the existing car-following models. Further studies are then always necessary to be done for making more convincing conclusions.

REFERENCES


