Steering Behavior during Overtaking on Freeways

Li Penghui, Hu Mengxia, Zhang Wenhui, Xu Xiaoqing, Li Yibing*
State Key Laboratory of Automotive Safety & Energy, Department of Automotive Engineering
Tsinghua University
Beijing, China
liyb@mail.tsinghua.edu.cn

Abstract—the steering behavior of lane change during overtaking on the freeway is experimentally investigated based on a six DOF moving-based driving simulator. 12 experienced participants are involved and instructed to overtake leading vehicles in specially designed scenarios, and their first lane changing of the overtaking is analyzed. The influence of type and speed of leading vehicle on steering behavior are explored by parametric tests. Results show that type of leading vehicle has no impact on steering behavior, including steering wheel amplitudes and duration of each phase. Speed of leading vehicle has significant influence on the first steering wheel amplitude, the second steering wheel amplitude and duration of first phase. This finding may help construct the lane change steering model on freeways with leading vehicle taken into consideration, and promote the freeway driving safety.

Keywords—steering; behavior; overtaking; lane change; freeway

I. INTRODUCTION

Lane changing is a common and evitable operation in daily driving. An inappropriate steering operation for lane changing may introduce a severe accident on freeways. Thus, it’s of great importance to investigate the steering behavior during lane changing for overtaking on freeways, which can be used for accident avoidance [1]. Plenty of studies have been conducted on steering control strategy for lane changing, which fall into two categories: with and without object in front of the lane changing vehicle. Summala [2] studied drivers’ steering maneuver with an obstacle in front of the vehicle, and found it to be related to the distance to the obstacle. While Reid, Solowska and Billing [3] found that the frontal obstacle has no influence on drivers’ steering behavior for lane change. Other studies [4] [5] without an object in front of the vehicle supposed that drivers prepare their steering maneuver in advance, and execute it with an appropriate force at the right moment, and at last compensate accumulate error with visual feedback. The initial amplitude was influenced by speed with an open-loop control, the second amplitude was acted as a compensation for close-loop control [6]. Despite all those previous efforts, it’s still lacking in the study on lane changing for overtaking, which features a leading vehicle (vehicle being overtaking) as an object in front of the lane changing vehicle.

In this work, the steering behavior of lane change during overtaking a leading vehicle on freeways is experimentally investigated based on a driving simulator. 12 participants are involved in the driving test, with the type and speed of leading vehicle varied, so as to explore their influence on drivers’ steering behavior.

II. METHODS

There were 12 subjects between 20 and 50 years old participated in this driving test, including 2 female drivers and 10 male drivers, all with at least 50 thousand kilometers’ driving experience. A series of parametric experiments is conducted continuously with a random order by each participant. Type of leading vehicle includes medium van and car, and speed of leading vehicle varies among 60, 80 and 100 km/h. totally each participant performed 18 lane changes, and 12 participants’ lane change data were analyzed and discussed here.

Figure 1 presents a typical time course of a lane changing maneuver from the center lane to the left lane, which records steering angle and vehicle lateral position. It shows that the steering wheel is first turned to left (left angle) till a maximum angle $P_{max1}$, then it is turned to the right (right angle) and return back to the initial position $P_{max2}$. The maneuver is divided into three phases for analysis [6] [8] [9]. The first phase $(0-t_{s1})$ lasts $T_1$ during which the steering wheel is turned to $P_{max1}$ (left angle). The second phase $(t_{s1}-t_{s2})$ lasts $T_2$, when the steering wheel is turned to zero. The third phase $(t_{s2}-t_{s3})$ lasts $T_3$, when the steering wheel is turned to the maximum $P_{max2}$ (right angle). The vehicle lateral position curve shows that the vehicle is gradually moving to the left lane without backswing during lane changing.

Figure 1. Time course of a lane changing maneuver.

$P_{max1}, P_{max2}, T_1, T_2$ and $T_3$ in the 216 lane changes were analyzed as indexes of steering behavior to explore the influence of the type and speed of leading vehicle. One-way
variance statistical method was adopted to test data correlation, and 0.05 level was set as the statistical significance value.

III. RESULTS

A. The maximum steering wheel angle $P_{max1}$ and $P_{max2}$

It is shown in Table 1 that $P_{max1}$ and $P_{max2}$ are significantly influenced by the speed of leading vehicle ($P_{max1}$: medium van, $F(2, 33) = 3.711$, $p = 0.038$; car, $F(2, 33) = 6.290$, $p = 0.007$; $P_{max2}$: medium van, $F(2, 33) = 3.400$, $p = 0.048$; car, $F(2, 33) = 4.154$, $p = 0.032$). With the speed of leading vehicle increased, $P_{max1}$ and $P_{max2}$ decrease gradually. However, $P_{max1}$ and $P_{max2}$ have no significant correlation with the type of leading vehicle ($P_{max1}$: 60 km/h, $F(1, 22) = 0.034$, $p = 0.856$; $P_{max2}$: 60 km/h, $F(1, 22) = 0.0001$, $p = 0.990$).

While the type of leading vehicle (60 km/h, $F(1, 33) = 0.016$, $p = 0.902$) of leading vehicle. Thus, it can be concluded that the type of leading vehicle (medium van or car) had no influence on the steering behavior for lane changing of overtaking on the freeways, the reason may be that medium van and car have not significant difference in size in the scenario in driving simulator, as a result there is little difference between the vision field and hazard that driver perceived in the two situations.

TABLE 1. STEERING BEHAVIOR CHANGE WITH LEADING VEHICLE

<table>
<thead>
<tr>
<th>project</th>
<th>speed and type of leading vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>type</td>
</tr>
<tr>
<td></td>
<td>speed(km/h)</td>
</tr>
<tr>
<td>$P_{max1}(\degree)$</td>
<td>mean</td>
</tr>
<tr>
<td>variance</td>
<td>13.4</td>
</tr>
<tr>
<td>$P_{max2}(\degree)$</td>
<td>mean</td>
</tr>
<tr>
<td>variance</td>
<td>92.8</td>
</tr>
<tr>
<td>$T_1$(s)</td>
<td>mean</td>
</tr>
<tr>
<td>variance</td>
<td>0.6</td>
</tr>
<tr>
<td>$T_2$(s)</td>
<td>mean</td>
</tr>
<tr>
<td>variance</td>
<td>0.4</td>
</tr>
<tr>
<td>$T_3$(s)</td>
<td>mean</td>
</tr>
<tr>
<td>variance</td>
<td>1.8</td>
</tr>
<tr>
<td>$V_f(\degree/s)$</td>
<td>mean</td>
</tr>
<tr>
<td>variance</td>
<td>217</td>
</tr>
</tbody>
</table>

B. The duration of each phase

Table 1 records $T_1$ and $T_3$ for various types and speeds of leading vehicle, which proves that neither type nor speed of leading vehicle has notable impact on $T_1$ (medium, $F(2, 33) = 0.095$, $p = 0.909$; 60 km/h, $F(1, 33) = 0.757$, $p = 0.396$) or $T_3$ (medium van, $F(2, 33) = 0.269$, $p = 0.766$; 60 km/h, $F(1, 33) = 0.853$, $p = 0.369$). While $T_3$ is significantly affected by the speed of leading vehicle for the case of medium van ($F(2, 33) = 3.434$, $p = 0.046$), $T_1$ decreases with the speed of the leading vehicle increasing. While $T_3$ is not significantly affected by the type of leading vehicle (60 km/h, $F(1, 22) = 0.732$, $p = 0.404$).

The mean angular velocity of steering wheel $V_f$ has no correlation with speed ($F(2, 33) = 1.194$, $p = 0.317$) or type ($F(1, 33) = 0.016$, $p = 0.902$) of leading vehicle.

IV. DISCUSSION

A. Speed of leading vehicle

The effect of leading vehicle’s speed on the first maximum steering wheel angle and the second maximum steering wheel angle are in line with the conclusion from W. van Winsum [7] that a higher speed result in a smaller initial and second steering wheel amplitude. Because the faster the leading vehicle is, the faster the overtaking vehicle is, so the maneuver response of smaller first maximum steering wheel in higher speed of leading vehicle is the maneuver response of higher speed of overtaking vehicle itself in essentially. Duration of the first phase decreases with speed of leading vehicle increased, while the mean angular velocity of steering wheel in first phase has no correlation with speed of leading vehicle.

So the reason why duration of first phase decreases with speed of leading vehicle increased is that the first amplitude decreased without prominent change of angular velocity of steering wheel. Thus in the first phase, drivers adjust steering wheel amplitude under different speeds of leading vehicle and the duration change with the amplitude.

Duration of the second and third phase had no relationship with the speed of leading vehicle, which may be related to time to line crossing (TLC) [7] in the second and third phase, the second steering angle serve as compensate movement to keep safety margins.

B. Type of leading vehicle

As shown above, no difference in $P_{max1}$, $P_{max2}$ and duration of each phase can be observed between medium van and car as the leading vehicle. Thus, it can be concluded that the type of leading vehicle (medium van or car) had no influence on the steering behavior for lane changing of overtaking on the freeways, the reason may be that medium van and car have not significant difference in size in the scenario in driving simulator, as a result there is little difference between the vision field and hazard that driver perceived in the two situations.

REFERENCES