A STUDY OF LANE-CHANGING BEHAVIOR MODEL AT WEAVING SECTION CONSIDERING CONFLICTS

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Abstract: This study proposes a lane changing behavior model at weaving section. When a mandatory lane-changing vehicle shifts from its original lane to the target lane on weaving section, the lane-changing vehicle must evaluate the conflict with the surrounding vehicles to change the lane safety. It is assumed that the lane-changing vehicle chooses acceleration or deceleration after evaluating the conflict between the surrounding vehicles. The lane-changing model is assumed to be composed two sub-models. The first model is the one describing the choice behavior between acceleration and deceleration using discriminant analysis. The second model represents the driver’s decision on acceleration / deceleration rate. This model is estimated by regression analysis. The discriminant function estimated can discriminate 78.9%, and the decelerate model’s parameter was estimated 0.37 of conflict variable and –0.29 of lane changing vehicle velocity. Finally, this research suggests a framework to evaluate traffic safety and road efficiency using a microscopic simulation including the model.

Key Words: TTC (Time to collision), PICUD (Possibility Index for Collision with Urgent Deceleration), lane-changing behavior model, AHS (Advanced cruise-assist Highway Systems), microscopic traffic simulation

1. INTRODUCTION

Recently, AHS (Advanced cruise-assist Highway System) has been developed for improving traffic safety and efficiency. It is expected that automating and coordinating vehicular controls using sensing, computer and communication technologies might lead to improvement of traffic safety and/or efficiency. Especially, severe conflicts between vehicles and accidents caused by some kind of human error might be drastically decreased. In order to put AHS into practical use in near future, it is necessary to develop a kind of engineering tool for evaluating the effects of AHS on safety and efficiency of traffic flow under conflicting traffic environment. Clearly, many conflicts between vehicles are occurring at weaving section because of a lot of mandatory lane-changing vehicles. So, this study focuses on vehicular...
behavior at weaving section and tries to develop a model representing lane-changing behavior considering traffic conflict. Most of the existing research works on lane-changing behavior treat just gap seeking behavior and gap acceptance. However, for evaluating the traffic conflicts in a suitable way, it is important to develop the speed adjustment models for lane-changing vehicle and following vehicle on target lane that can be applied for the entire lane-changing process.

This study proposes a lane changing behavior model at weaving section. When a mandatory lane-changing vehicle shifts from its original lane to the target lane on weaving section using limited time and space given, the driver of lane-changing vehicle must evaluate the conflict with surrounding vehicles to change its traveling lane safely. It is assumed that the lane-changing vehicle chooses acceleration or deceleration after evaluating the conflict with the surrounding cars. In this study, the mandatory lane-changing behavior is assumed to consist of the following two steps. Firstly, a driver of lane-changing vehicle is assumed to decide whether he/she should make acceleration or deceleration to prevent a collision with the most dangerous vehicles based on his/her subjective evaluation on the traffic conflict. Secondly, it is assumed that he/she adjust acceleration or deceleration rate based on the severity of vehicular conflicts. The framework mentioned above is adopted for modeling the mandatory lane-changing behavior in this study. A simple microscopic simulation model including the model of lane-changing behavior is applied for evaluating the effects of partially automating and coordinating vehicular controls upon safety and efficiency of traffic flow.

2. DATA

Figure 1 shows a schematic chart of weaving section to be studied. The studied weaving section is located in the eastern suburb of Kyoto City and on the borderline between Kyoto and Shiga Prefectures. Also the weaving section is regarded as one of the important places for road transportation, because at the weaving section shown in figure 1 two major national highways, National Highway 1 and National Highway 161 merge. Around 150 meters ahead of the merging point, the road section is divided again into National Highway 1, Sanjo Street that is connected to CBD of Kyoto city and the on-ramp of Meishin expressway. This is a very busy and dangerous weaving section and a lot of conflicts between vehicles can be easily observed. A committee for improving traffic safety organized by Ministry of Land, Infrastructure and Transport and Police Agency of Kyoto Prefecture also analyzed the weaving section and suggested some measures to reduce traffic accidents here.

This study uses the video recordings of traffic flow at the weaving section from 15:00 to 18:00 on May 25 1999. Especially, the video images recorded by Video Camera A in figure
1 are adopted for analyzing the vehicular movements in the studied section in a microscopic manner. Video Camera $A$ can record the vehicular movement from the rear side of each vehicle, and hereby it is possible for us to distinguish the vehicle that applies brake from others by its brake lamp.

Table 1 shows the observed hourly traffic volumes classified by inlet and outlet of the traffic. The 3 hours traffic volumes of National Highway 1 and 161 are 3152 and 3446 respectively. The vehicles traveling from National Highway 161 to CBD of Kyoto city, of which number is 104, are required to make lane-change in this weaving section of which length is only 150 meters. In other words, the lane-changes done by the vehicles from National Highway 161 to CBD of Kyoto city are regarded as the mandatory lane-changes. It is not so difficult for us to imagine that these mandatory lane-changes often cause the conflicts between vehicles. This study concentrates on the analyses of these mandatory lane-changes and the related conflicts.

Table 1. Observed Hourly Traffic Volumes at Studied Section (Veh/hour)

<table>
<thead>
<tr>
<th>Flow out</th>
<th>National Highway 1</th>
<th>Sanjo Street</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Highway 1</td>
<td>1797</td>
<td>1355</td>
<td>3152</td>
</tr>
<tr>
<td>National Highway 161</td>
<td>3036</td>
<td>410</td>
<td>3446</td>
</tr>
<tr>
<td>Total</td>
<td>4833</td>
<td>1765</td>
<td>6598</td>
</tr>
</tbody>
</table>

The microscopic data on vehicular trajectories are obtained by a computerized tool on MS-Windows to trace vehicular movement from the digital video images of traffic flow. This tool can show us on the computer display the still image of any frames of the video about traffic flow. Using a computer mouse, it is possible for us to obtain the coordinates of any points in the image. Equation (1) below can convert the coordinates in the video image into the real field coordinates. Therefore the tool provides us with the data of vehicle location in every 0.5 seconds on the real field coordinates.

$$Y = \frac{a_U + a_V + 1}{a_U + a_V + a_z} + Y_0$$

$Y$ represents the estimated location of vehicle on the real field coordinates. $U$ and $V$ represent the vehicle location on the coordinates in the video image. $Y_0$ indicates the location of video camera on the real field coordinates and it should be estimated. $a_1, \cdots, a_z$ are the estimated parameters. We conducted the field survey to grasp the location of some landmarks recorded in the video image on the real field coordinates. The least square method provides us with the estimates of the parameters $a_1, \cdots, a_z$ and $Y_0$ based on the surveyed landmark locations. Due to the limitation of surveyed locations of landmark, it is assumed that only the vehicle location on $Y$-axis is explicitly considered in this study. Here $Y$-axis corresponds with the direction of vehicle moving. One of the analytical targets of this study is to clarify how the lane-changing vehicle may adjust its velocity. Accordingly, the vehicle location on $Y$-axis provides us with the useful information for pursuing this analytical target. It is clear that the data of vehicle location can be converted into vehicle velocity and temporal change in velocity (acceleration) easily.

Figure 2 represents a typical lane-changing situation studied in this study and the notations of the lane-changing vehicle and its surrounding vehicles. (LCV: lane-changing vehicle, LV: a leading vehicle, FV: a following vehicle, LVA: a leading vehicle on accepting lane, FVA: a following vehicle on accepting lane of lane changing vehicle)
Figure 2. Typical Lane-changing Situation Studied

Due to the diversity of driver’s judgment and maneuvering vehicle, it is very difficult for us to find clear statistical relation in Figure 3(a) to (d) and Figure 4(a) to (d) except for Figure 4(c). In Figure 4(c), there is a relatively strong relation between the data representing decelerating situation and the relative velocity with its LVA, because $\rho_{\text{dec}}$ becomes $-0.54$. In other figures, there are very weak correlation between the data representing accelerating situation, the distance headway and relative velocity. In other words, it might be possible for us to make a statistical model to estimate the deceleration rate only. This is a reason why this study adopts the modeling framework consisting of two different steps mentioned above for representing the lane-changing behavior.
Between a following vehicle

\[
\begin{align*}
\rho_{\text{acc}} &= -0.15 \\
\rho_{\text{dec}} &= 0.44
\end{align*}
\]

Figure 3(b). Correlation Coefficient between Acceleration Rate of LCV and Distance Headway of FV

Between a leading vehicle on accepting lane

\[
\begin{align*}
\rho_{\text{acc}} &= 0.04 \\
\rho_{\text{dec}} &= -0.05
\end{align*}
\]

Figure 3(c). Correlation Coefficient between Acceleration Rate of LCV and Distance Headway of LVA

Between a following vehicle on accepting lane

\[
\begin{align*}
\rho_{\text{acc}} &= -0.07 \\
\rho_{\text{dec}} &= 0.12
\end{align*}
\]

Figure 3(d). Correlation Coefficient between Acceleration Rate of LCV and Distance Headway of FVA

Figure 4(a). Correlation Coefficient between Acceleration Rate of LCV and relative velocity with LV

\[ \rho_{\text{acc}} = 0.24 \]
\[ \rho_{\text{dec}} = -0.16 \]

Figure 4(b). Correlation Coefficient between Acceleration Rate of LCV and relative velocity with FV

\[ \rho_{\text{acc}} = 0.11 \]
\[ \rho_{\text{dec}} = -0.22 \]

Figure 4(c). Correlation Coefficient between Acceleration Rate of LCV and relative velocity with LVA

\[ \rho_{\text{acc}} = 0.10 \]
\[ \rho_{\text{dec}} = -0.54 \]
OBJECTIVE INDICES TO EVALUATE TRAFFIC CONFLICT

Traffic conflict methods have been studied to identify accident potential and operational problems at a road section. Since the General Motors Research (GMR) laboratories proposed an analysis of traffic conflict in 1967, many researchers and traffic engineers have proposed this kind of analytical methods. Hayward suggested that TTC (Time to collision) between two vehicles involved in a hazardous event could be employed as a reasonable scale to judge the severity of near-miss cases. TTC can be calculated by equation (2) below. Allen et al. pointed out that TTC cannot be calculated when the leading vehicle’s velocity is higher than that of its follower, and introduced seven methods for defining conflict situations. Iida et al. proposed PICUD (Possibility Index for Collision with Urgent Deceleration), which is an index to evaluate the possibility that two consecutive vehicles might collide assuming that the leading vehicle applied its emergency brake. The equation (3) shows the way to calculate PICUD.

\[
TTC(\text{sec}) = \frac{s_0}{V_2 - V_1}
\]

\[
PICUD(\text{m}) = \frac{V_1^2 - V_2^2}{2\alpha} + s_0 - V_2 \Delta t
\]

Here, \(V_1, V_2\) : velocity of leading car 1 and following car 2, respectively
\(s_0\) : distance between car 1 and 2
\(\Delta t\) : driver’s reaction time
\(\alpha\) : deceleration rate to stop.

In this study, a very simple simulation representing lane-changing behavior on a two-lane road section is conducted for comparing TTC with PICUD. In order to analyze the relation between the number of lane-changing vehicles and the traffic conflict, this study conducted two cases of simulation with different number of lane-changing vehicles. The simulation settings indicating traffic volume and velocity on each lane are as follows.

**Case1**
- Volume of accepting lane: 0.22Veh/sec, Velocity: 27.78m/sec
- lane changing volume: 0.03Veh/sec, Velocity: 27.78m/sec

**Case2**

Figure 4(d). Correlation Coefficient between Acceleration Rate of LCV and relative velocity with FVA
Volume of accepting lane: 0.22 Veh/sec, Velocity: 27.78 m/sec
Lane changing volume: 0.14 Veh/sec, Velocity: 27.78 m/sec

Figure 5 shows the simulation results expressed by the cumulative percentage of minimum TTC and PICUD every 100m-road section. Though it is expected that the increase in lane-changing vehicles might lead to the increase in vehicular conflicts, it can be said that there is not a clear difference in the minimum TTC between case 1 and case 2. If PICUD is applied for evaluating the traffic conflicts, it can be said that Case 2 is more conflicted than Case 1. In other words, there is a possibility that PICUD might detect the change in traffic condition and conflicts more sensitively than TTC. Based on the discussion above, PICUD is adopted for evaluating traffic conflicts in this study.

Figure 5. Simulation Results for Comparing TTC with PICUD

4. ANALYSIS BETWEEN LANE CHANGING BEHAVIOR AND CONFLICT

The ANOVA analysis was applied to find the relation between lane-changing behavior to adjust velocity and traffic conflicts evaluated. PICUD was calculated for the inter-vehicular relation between the lane-changing vehicle and its surrounding vehicles: LV, FV, LVA and FVA. Accelerating and decelerating are assumed to be the change in velocity from starting time to terminating time of lane-changing process. Table 1 summarizes PICUD values classified by accelerating or decelerating situations of lane-changing vehicle, individually. There are differences in PICUD of LV and LVA between accelerating situation and
decelerating one. Judging from the calculated PICUD in Table 2, it can be said that the driver of lane-changing vehicle tends to pay more attention to the vehicle in front than its following vehicles. Also, under the situation with more conflicts, the driver tends to decelerate his / her vehicle.

Table 2. Summary of PICUD between Lane-changing Vehicle and Its Surrounding Vehicles

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>20</td>
<td>26</td>
<td>17</td>
<td>24</td>
<td>55</td>
<td>39</td>
<td>41</td>
<td>27</td>
</tr>
<tr>
<td>Total</td>
<td>58.2</td>
<td>465.0</td>
<td>320.8</td>
<td>274.6</td>
<td>519.4</td>
<td>984.6</td>
<td>956.2</td>
<td>676.8</td>
</tr>
<tr>
<td>Average (m)</td>
<td>2.9</td>
<td>17.9</td>
<td>18.9</td>
<td>11.4</td>
<td>9.4</td>
<td>25.2</td>
<td>23.3</td>
<td>25.1</td>
</tr>
<tr>
<td>Standard Dev. (σ)</td>
<td>8.8</td>
<td>20.0</td>
<td>12.7</td>
<td>12.1</td>
<td>16.9</td>
<td>17.2</td>
<td>19.3</td>
<td>13.5</td>
</tr>
<tr>
<td>Average +σ</td>
<td>11.7</td>
<td>37.9</td>
<td>31.5</td>
<td>23.5</td>
<td>26.3</td>
<td>42.5</td>
<td>42.6</td>
<td>38.6</td>
</tr>
<tr>
<td>Average –σ</td>
<td>-5.8</td>
<td>-2.1</td>
<td>6.2</td>
<td>-0.6</td>
<td>-7.4</td>
<td>8.0</td>
<td>4.0</td>
<td>11.5</td>
</tr>
</tbody>
</table>

ANOVA method is applied to confirm the statistical difference in PICUD between accelerating and decelerating situations. The result of ANOVA is shown in Table 3. For LV and LVA, it is possible for us to reject the hypothesis that there is no significant difference in PICUD between accelerating situation and decelerating one. There is a possibility that PICUD of lane-changing vehicle with LV or LVA might be used as an explanatory variable of the lane-changing model.

Table 3. Result of ANOVA

<table>
<thead>
<tr>
<th>Factor</th>
<th>Sum of partial deviation square</th>
<th>df</th>
<th>Mean square</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV</td>
<td>2533.46</td>
<td>1</td>
<td>2533.46</td>
<td>9.36</td>
<td>0.00377 **</td>
</tr>
<tr>
<td>Error</td>
<td>11912.18</td>
<td>44</td>
<td>270.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14445.64</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FV</td>
<td>549.19</td>
<td>1</td>
<td>549.19</td>
<td>3.45</td>
<td>0.07091</td>
</tr>
<tr>
<td>Error</td>
<td>6212.81</td>
<td>39</td>
<td>159.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>6762.01</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVA</td>
<td>5698.57</td>
<td>1</td>
<td>5698.57</td>
<td>19.28</td>
<td>0.00003 **</td>
</tr>
<tr>
<td>Error</td>
<td>27195.56</td>
<td>92</td>
<td>295.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>32894.13</td>
<td>93</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FVA</td>
<td>49.63</td>
<td>1</td>
<td>49.63</td>
<td>0.16</td>
<td>0.68857</td>
</tr>
<tr>
<td>Error</td>
<td>20210.65</td>
<td>66</td>
<td>306.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20260.28</td>
<td>67</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**: means significant level at α = 0.01

5. MODELLING THE LANE CHANGING BEHVIOR

As mentioned in introduction of this study, the lane-changing behavior model is built using the framework composed of two different sub-models. The first model represents the driver’s decision whether he / she chooses acceleration or deceleration after evaluating the traffic conflicts. The second model represents the driver’s decision on acceleration / deceleration rate.
The discriminant analysis is applied for estimating the first model shown in equation (4). And the regression analysis is used for estimating the second model indicated by equation (5).

\[ f_{mode} = \sum_{j=1}^{M} \sum_{i=1}^{K} \phi_{ij} X_{ij} \quad (4) \]

\[ \dot{v}_{mode} = \sum_{\alpha=1}^{N} \sum_{\beta=1}^{L} \zeta_{\alpha\beta} X_{\alpha\beta} \quad (5) \]

Here,

- \( mode \): acceleration / deceleration mode
- \( \phi_{ij} \): parameter of variable \( j \) of vehicle \( i \)
- \( i \): vehicles
- \( j \): variable
- \( \dot{v}_{mode} \): acceleration / deceleration rate
- \( \zeta_{\alpha\beta} \): parameter of variable \( \beta \) of vehicle \( \alpha \)
- \( \alpha \): chosen vehicles through step1
- \( \beta \): chosen variable through step1

The result of first model is indicated in Table 4. 78.9% of data can be discriminated properly by the model shown in Table 4. Accordingly, it can be concluded that the goodness of fit corresponds to ‘well estimated’ on the 3 steps (very well, well, not good). The statistically significant variables are LCV (lane changing vehicle)’s velocity and the PICUD value between LVA (a leading vehicle on accepting lane) and lane changing vehicle. As discussed above, there is a strong possibility that PICUD between LCV and LVA might affect the driver’s decision whether he / she chooses acceleration or deceleration. The LCV’s velocity parameter and PICUD parameter become -0.83 and 0.53 respectively.

Table 4. Discriminant Analysis for the First Model

<table>
<thead>
<tr>
<th>Discriminate Group</th>
<th>Sample</th>
<th>Discriminate (%)</th>
<th>Wilk’s Lamda</th>
<th>F-Value (3,101)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration</td>
<td>43</td>
<td>67.4</td>
<td>0.66</td>
<td>26.72</td>
<td>0.0000</td>
</tr>
<tr>
<td>Deceleration</td>
<td>62</td>
<td>90.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total; 105</td>
<td>Average; 78.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Parameter Estimation

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Variables</th>
<th>Normal discriminate coefficient (Eigen value=0.52)</th>
<th>Wilk’s Lamda</th>
<th>F-Value (1,102)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCV</td>
<td>Velocity</td>
<td>-0.83</td>
<td>0.86</td>
<td>21.33</td>
<td>0.0000</td>
</tr>
<tr>
<td>LVA</td>
<td>PICUD Value</td>
<td>0.53</td>
<td>0.73</td>
<td>10.93</td>
<td>0.0013</td>
</tr>
</tbody>
</table>

The estimated results of the second model representing the driver’s decision on acceleration / deceleration rate are shown in Table 5 and 6. Table 5 shows the model exclusively used for accelerating situation. Table 6 shows the model designated for decelerating situation.
The second model used for accelerating situation is not statistically good due to a very low multiple correlation. As mentioned above, in the driving environment where the driver can choose acceleration, the vehicular maneuvering might not be strongly restricted. There is a possibility that the diversity of driver’s decision reveals clearly under such situation. This is one of possible reasons why the second model used for accelerating situation is not statistically good.

### Table 5. Regression Analysis for the Second Model (Accelerating Situation)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Sum of mean square</th>
<th>df</th>
<th>Mean square</th>
<th>F-Value</th>
<th>P-Value</th>
<th>R-square</th>
<th>Multiple correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>0.00</td>
<td>2</td>
<td>0.0014</td>
<td>1.61</td>
<td>0.2119</td>
<td>0.08</td>
<td>0.28</td>
</tr>
<tr>
<td>Residual</td>
<td>0.03</td>
<td>39</td>
<td>0.0009</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.04</td>
<td>41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Parameter Estimation

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Variables</th>
<th>Parameter</th>
<th>T-Value</th>
<th>F-Value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCV</td>
<td>Velocity</td>
<td>-0.28</td>
<td>1.80</td>
<td>3.23</td>
<td>0.0801</td>
</tr>
<tr>
<td>LVA</td>
<td>PICUD</td>
<td>-0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.9940</td>
</tr>
</tbody>
</table>

Judging from the multiple correlation in Table 6, it can be said that the second model designated for decelerating situation is not so statistically good. However, each explanatory variable becomes statistically significant, thereby based on the estimated result, we try to analyze the driver’s mechanism to determine the deceleration rate. It can be concluded that LCV’s velocity and PICUD of LCV with LVA might affect the driver’s mechanism to determine the deceleration rate.

### Table 6. Regression Analysis for the Second Model (Decelerating Situation)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Sum of mean square</th>
<th>df</th>
<th>Mean square</th>
<th>F-Value</th>
<th>P-Value</th>
<th>R-square</th>
<th>Multiple correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>0.03</td>
<td>2</td>
<td>0.02</td>
<td>8.63</td>
<td>0.0005</td>
<td>0.23</td>
<td>0.48</td>
</tr>
<tr>
<td>Residual</td>
<td>0.10</td>
<td>58</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.13</td>
<td>60</td>
<td></td>
<td></td>
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</table>

### Parameter Estimation

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Variables</th>
<th>Parameter</th>
<th>T-Value</th>
<th>F-Value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCV</td>
<td>Velocity</td>
<td>-0.29</td>
<td>2.52</td>
<td>6.33</td>
<td>0.0009</td>
</tr>
<tr>
<td>LVA</td>
<td>PICUD Value</td>
<td>0.37</td>
<td>3.16</td>
<td>3.16</td>
<td>0.0025</td>
</tr>
</tbody>
</table>
6. SUGGESTION OF IT’S APPLICATION

The road safety and efficiency are assessed using microscopic simulation model into which the two-step lane-changing model is incorporated. The road section studied is composed of 2 lanes and one of them is closed 300m ahead from the upstream end (shown in Figure 6). If a vehicle reaches the lane-closure section, it should be ready for moving to the other lane (the first lane changing condition). If the lane-changing vehicle cannot find the suitable gap, it must wait for the coming acceptable gap. The data of the weaving section mentioned above are referred to as gap distribution. This study applies a well-known car-following model, namely GM (General Motors group)’s first model in order for describing the movement of vehicles except for the lane-changing vehicle. The traffic conflict is evaluated in terms of the frequency of negative values of PICUD simulation time on each 100m section, and the efficiency is evaluated by the estimated traffic volume. The diversity of vehicular response time can be described by normal distribution in the simulation.

\[
P = \frac{\sum C_j}{\sum Q_j}
\]

\(C_j\) : Counted minus PICUD value on time road \(j\)

\(Q_j\) : Counted volume for simulation time road \(j\)

The first case study is implemented for 3 cases where the reaction time is assumed 1.0sec, 1.5sec and 1.8sec. Table 1 shows result. It summarizes the relation between the frequency of conflict, road section and the reaction time. The lane-changes are observed mainly in section III(200~300m), and thereby the conflict increases around the 300m section. It can be said that reaction time tends to reduce the conflict. In the case of response time being 1.0sec, the number of conflicts observed is minimum compared with other cases. In the second case study, it is assumed that the following vehicle’s velocity is controlled and coordinated. In this case, in average 16km/hr of velocity reduction of the following vehicle is assumed in order for expanding the gap into where the lane-changing vehicle moves. In the normal case, the corresponding velocity reduction is assumed 9km/hr. The result is shown here averaged value of 5 times simulation. As shown in table2, reducing the velocity of the following vehicle might lead to a little increase in the conflict and on non-closed lane and a drastic decrease in the control on the closure lane.
Table 7. Result of the case study 1

<table>
<thead>
<tr>
<th>Section</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response time</td>
<td>≤100m</td>
<td>1.8</td>
<td>1.5</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>(77.3/41.7)</td>
<td>(63.7/40.3)</td>
<td>(78.3/38.7)</td>
<td>(125.7/37.0)</td>
<td>(71.0/33.7)</td>
</tr>
<tr>
<td>1.8 sec</td>
<td>1.6</td>
<td>0.4</td>
<td>0.2</td>
<td>0.7</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>(40.7/42.3)</td>
<td>(16.7/41.3)</td>
<td>(69.3/39.3)</td>
<td>(42.7/35.3)</td>
<td>(31.0/33.3)</td>
</tr>
<tr>
<td>1.5 sec</td>
<td>0.7</td>
<td>0.0</td>
<td>0.2</td>
<td>0.7</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>(25.0/36.7)</td>
<td>(1.0/36.3)</td>
<td>(6.7/36.0)</td>
<td>(42.7/35.3)</td>
<td>(31.0/33.3)</td>
</tr>
<tr>
<td>1.0 sec</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>(125.7/37.0)</td>
<td>(181.0/37.3)</td>
<td>(168.3/33.7)</td>
<td>(226.8/38.0)</td>
<td>(188.6/35.8)</td>
</tr>
</tbody>
</table>

And waiting time of lane changing vehicle is reduced averaged 5.6sec to 0.4sec by velocity control. It can be said that the control of following vehicle’s velocity might lead to improving the closed lane’s safety, but getting poor about on the non-closed lane’s safety. It needs more experimentation to find optimum situation on this case.

Table 8. Result of the case study 2

<table>
<thead>
<tr>
<th>Lane</th>
<th>Control situation</th>
<th>I ≤100m</th>
<th>II 100~200m</th>
<th>III 200~300m</th>
<th>IV 300~400m</th>
<th>V 400~500m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Non-Controlled</td>
<td>1.4</td>
<td>2.0</td>
<td>3.5</td>
<td>5.9</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(55.2/39.8)</td>
<td>(76.8/38.8)</td>
<td>(133.0/37.6)</td>
<td>(211/36)</td>
<td>(152.0/34.2)</td>
</tr>
<tr>
<td></td>
<td>Controlled</td>
<td>2.3</td>
<td>3.2</td>
<td>4.7</td>
<td>6.0</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(90/40)</td>
<td>(126.8/39.2)</td>
<td>(182.0/38.6)</td>
<td>(226.8/38.0)</td>
<td>(188.6/35.8)</td>
</tr>
<tr>
<td>2</td>
<td>Non-Controlled</td>
<td>9.1</td>
<td>12.9</td>
<td>22.2</td>
<td>Closed</td>
<td>Closed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(139.6/15.4)</td>
<td>(146.6/11.4)</td>
<td>(244.2/11.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Controlled</td>
<td>4.8</td>
<td>2.0</td>
<td>1.7</td>
<td>Closed</td>
<td>Closed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(75.6/15.8)</td>
<td>(30.6/15.0)</td>
<td>(24.2/14.2)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. CONCLUSIONS

This study proposes a lane changing behavior model at weaving section. When a mandatory lane-changing vehicle shifts from its original lane to the target lane on weaving section, the lane-changing vehicle must evaluate the conflict with the surrounding vehicles to change the lane safety. It is assumed that the lane-changing vehicle chooses acceleration or deceleration after evaluating the conflict between the surrounding vehicles. The lane-changing model is assumed to be composed two sub-models. The first model is the one describing the choice behavior between acceleration and deceleration using discriminant analysis. The second model represents the driver’s decision on acceleration / deceleration rate. This model is estimated by regression analysis. The discriminant function estimated can discriminate 78.9%, and the decelerate model’s parameter was estimated 0.37 of conflict variable and ~0.29 of lane changing vehicle velocity. Finally, this research suggests a framework to evaluate traffic safety and road efficiency using a microscopic simulation including the model.

Also this research proposes a framework to evaluate traffic safety and road efficiency when the control system is applied, like AHS. It could be assessed to control of reduce reduction time and velocity of following car. But, it is needed to add more capability to microscopic simulation, it should be considered by the future study.
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