Studies on Vehicle Guidance and Control

HANS GODTHELP, GERARD J. BLAAUW, and JAN MORAAL

ABSTRACT

For approximately 10 years, part of the research effort of the TNO Institute for Perception has been devoted to the analysis and modeling of driving behavior. In this paper, some of the most relevant research issues in this area will be reviewed. First, an impression is given of some theoretical and experimental studies on course perception and vehicle guidance in preview. Second, two nearly developed methods for describing vehicle control as a supervisory task are discussed. The predictions made with these models were verified in a field experiment in which subjects drove under conditions with temporary occlusion of visual input at different speed levels. Subjects' self-chosen occlusion durations could very well be explained by both models. Suggestions are given of how the proposed methods can be applied to optimize roadway and vehicle characteristics.

VEHICLE GUIDANCE

Much of the research into the basic perceptual cues in driving has been concerned with the perception of owner vehicle movements (i.e., the perception of course and speed) for the straight road situation. Instead of starting from a bird's-eye view description, which is the common approach in most of the presently available driver models (1-4), the purpose has been to describe and analyze the situation from a perspective view of the road ahead. Figure 1 shows an impression of the driver's visual scene looking ahead on a straight road marked with continuous lines.

In this figure, a lateral position deviation, $\Delta y$, can be optically perceived by the driver as an angular deviation $\Delta \alpha$. The ratio between $\Delta \alpha$ and $\Delta y$ gives a theoretical estimate of the driver's sensitivity for the perception of lateral position deviations. This ratio changes as a function of (a) the driver's eye height above the delineation, $h$, and (b) the driver's lateral distance to the delineation, $y$, according to Equation 1 as follows:

$$\frac{\Delta \alpha}{\Delta y} = \frac{h}{h^2 + y^2}$$

(1)

Figure 2 shows a representation of Equation 1, illustrating the effect of four road delineation systems on the driver's theoretical sensitivity for lateral deviations. The four delineation systems are panel-mounted ($L_1$ and $L_2$, respectively, with relative eye heights $h = -0.10 \text{ m}$ and $h = 0.40 \text{ m}$), post-mounted ($L_3$, with $h = 0.75 \text{ m}$), and pavement ($L_4$, with $h = 1.25 \text{ m}$).

This analysis turns out to be of great help in understanding and explaining real-world observations, in predicting the kind of difficulties that may arise, for instance, with work-zone delineation systems, and in making recommendations. Schwab and...
Capelle (6), for example, found that centerline delineation is highly cost-effective in terms of accident rates and driving performance. In a laboratory experiment, Godthelp and Riemersma (7) showed that there is a large effect of delineation systems varying in height on subjects' error percentages when they judged the simulated work-zone geometries shown in Figure 3. Furthermore, the results, which are presented in Figure 4, show that disturbances such as having some delineators removed from the scene (as is often the case in real situations) may strongly affect the error score. Response times of subjects were also in line with these findings; the higher the eye height above delineation, the shorter the response times in judging work-zone geometry.

The latter findings point to the effect of road delineation on the driver's preview, which is of utmost relevance for anticipation of the road geometry ahead. Early anticipation will allow timely steering performance and so will contribute to traffic safety.

VEHICLE CONTROL

One of the main tasks of the driver when steering his vehicle along the road or through a terrain is to control lateral position. Most of the available steering control models are based on the assumption that the driver acts as an error-correcting mechanism continually allocating attention to the steering task. However, driving cannot simply be considered to be a continuous closed-loop task. First, the driving task does not require permanent error control; second, the driver is sometimes forced to pay attention to aspects other than steering, so that it...
The Optimal Control Model (OCM)

The OCM describes the driver as a combined observer-predictor, controller, and decision maker (Figure 7), thus enabling the prediction of the observation and control strategy of the driver acting as a multitask system supervisor (14).

TLC Predictions

Median and 15th-percentile TLC values were calculated together with means and standard deviations of lateral position, lateral speed, and steering wheel angle. Table 1 gives the results of these measures for six different speed conditions. Of main interest,
FIGURE 6 Sample time history of TLC (a), resulting from the corresponding lateral position (b), lateral speed (c), and steering-wheel angle (d).

FIGURE 7 Structure of the supervisory driver model (14).
TABLE 1  Lateral Position, Lateral Speed, and Steering Wheel Angle Values as Affected by Vehicle Speed and Visual Occlusion (15)

<table>
<thead>
<tr>
<th>Speed (kph)</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral position occlusion (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1.75</td>
<td>1.78</td>
<td>1.81</td>
<td>1.86</td>
<td>1.94</td>
<td>1.94</td>
</tr>
<tr>
<td>With</td>
<td>1.80</td>
<td>1.78</td>
<td>1.76</td>
<td>1.82</td>
<td>1.77</td>
<td>1.88</td>
</tr>
<tr>
<td>Without</td>
<td>0.26</td>
<td>0.23</td>
<td>0.25</td>
<td>0.23</td>
<td>0.23</td>
<td>0.24</td>
</tr>
<tr>
<td>Standard deviation (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With</td>
<td>0.12</td>
<td>0.13</td>
<td>0.16</td>
<td>0.15</td>
<td>0.16</td>
<td>0.16</td>
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<tr>
<td>Without</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Lateral speed</td>
<td></td>
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<td></td>
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<tr>
<td>Standard deviation (cm/sec)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With</td>
<td>6.6</td>
<td>7.6</td>
<td>9.4</td>
<td>10.1</td>
<td>11.9</td>
<td>12.5</td>
</tr>
<tr>
<td>Without</td>
<td>2.3</td>
<td>3.7</td>
<td>5.1</td>
<td>6.0</td>
<td>6.7</td>
<td>8.0</td>
</tr>
<tr>
<td>Steering wheel angle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviation (degrees)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With</td>
<td>3.0</td>
<td>2.0</td>
<td>1.7</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Without</td>
<td>1.2</td>
<td>0.9</td>
<td>0.9</td>
<td>1.0</td>
<td>1.1</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Note: kph = kilometers per hour.

FIGURE 8 Median and 15th-percentile TLC-values as a function of vehicle speed and for runs with and without occlusion.

However, is the relation between the data of Table 1 and the TLC measure by which lateral position, speed, and steering wheel data can be integrally evaluated. Figure 8 shows that TLC is relatively large for low speeds and becoming less dependent on speed when speed increases.

The major reason for developing a time-related measure such as TLC was an interest in the relation between this measure and drivers' open-loop performance (i.e., the duration of the self-chosen occlusion intervals). The relationship between the 15 percent TLC level and the mean of the occlusion times is shown in Figure 9, thus illustrating the potential power of the TLC measure as a predictor of the driver's occlusion strategy.

Figure 10 shows a hypothetical time history of a driver's visual sampling behavior and corresponding TLC. It is clear that, just before the request for a new visual input, there is spare time before which the vehicle would have reached either one of the lane delineations. Hence, this spare time, noted as $T_{occ}$, combined with $T_{occe}$ gives the total time available from the start of the occlusion period until the moment one of the lane boundaries would have been reached.

An interesting finding concerns the ratio between $T_{occ}$ and the sum of $T_{occe}$ and TLC, the results of which are given in Table 2. It is evident from the data in Table 2 that this ratio appears to be remarkably constant over a large range of vehicle speeds (no significant differences; $p > 0.20$).

FIGURE 9 Means of occlusion times, $T_{occ}$, and 15th-percentile TLC-values.
figure 10 Hypothetical time history of a driver’s visual sampling behavior and corresponding TLC, illustrating the points at which TLC \(_0\) values are determined.

<table>
<thead>
<tr>
<th>Speed (kph)</th>
<th>(T_{\text{occ}} (s))</th>
<th>(TLC_{\text{a}} (s))</th>
<th>(T_{\text{occ}} / (T_{\text{occ}} + TLC_{\text{a}}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>5.32</td>
<td>8.88</td>
<td>0.37</td>
</tr>
<tr>
<td>40</td>
<td>4.23</td>
<td>6.33</td>
<td>0.40</td>
</tr>
<tr>
<td>60</td>
<td>3.45</td>
<td>5.32</td>
<td>0.40</td>
</tr>
<tr>
<td>80</td>
<td>3.15</td>
<td>4.77</td>
<td>0.41</td>
</tr>
<tr>
<td>100</td>
<td>2.67</td>
<td>4.35</td>
<td>0.39</td>
</tr>
<tr>
<td>120</td>
<td>2.38</td>
<td>3.14</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Note: kph = kilometers per hour.

figure 11 Predicted standard deviations of lateral position (via \(a\)) as a function of observation noise level for six combinations of display variables.
It is also clear that more display variables can be weighed according to the optimization criterion in the control block than lateral position alone. Addition of lateral speed only has a marginal effect; yaw rate or both acceleration cues may lead to a 5-10 cm deterioration in standard deviation of lateral position.

The model analysis can be used for the prediction of free periods in the observation strategy while controlling lateral position. Those free periods are reflected by voluntarily chosen visual occlusion durations. During occlusion periods, the driver's estimate of the state of the vehicle has to be based on knowledge of the previously observed display variables and the estimation error will increase as a function of occlusion duration.

Figure 12 gives model predictions for standard deviations of lateral position as a function of occlusion time, for several combinations of display variables.

Larger occlusion durations correspond with larger standard deviations of lateral position. Lateral acceleration, $a_1$, and yaw acceleration, $r$, both contribute to much slower deterioration of control performance. Additional weighing of a contributes to considerable increase in occlusion durations (curves 5 and 6). Figure 13 shows occlusion time as a function of driving speed for various levels of constant standard deviations of lateral position (i.e., the uncertainty the driver is willing to accept).

The data in Figure 13 are assumed to represent driving behavior of experienced subjects using all available information (i.e., the five display variables) for observation and control. A standard deviation level of 0.15 m reflects nonoccluded observation or an occlusion duration of 0 sec. The 0.31-m level indicates the limit in lateral variation due to a 3.60-m lane width.

The predictions of Figure 13 can be compared with empirically found occlusion durations. It appeared that the OCM enables predictions of empirical occlusion durations within one standard deviation: the correlation between the data of Figure 14 is considerable ($r = 0.97$). Hence, it is conceivable that experienced drivers indeed use all five display variables for observation and control. (Note that in Figure 14, the field data present mean values and standard deviations of measured occlusion durations of experienced drivers.)

**DISCUSSION**

Both TLC and OCM analyses appear to be valid methods for the description of automobile driving in terms of a supervisory task.
visual sampling strategy related to driving speed, measure of driving behavior, predictions on driver's occlusion. With regard to the latter possibility, it and a description of the relation between self-chosen occlusion durations and the total time available for occlusion. With regard to the latter possibility, it is indeed remarkable that drivers tend to use a constant proportion, approximately 40 percent, of the total available time rather than leave a constant amount of spare time at the end of the occlusion interval.

The OCM analysis enables evaluation of the potential role of various combinations of perceptual cues in driving. Use of the lateral speed cue in the observation-prediction block generally resulted in improved driving performance (i.e., smaller standard deviations in lateral position). Otherwise stated, when using the lateral speed cue drivers have more time to anticipate, while keeping control performance at the same level. Riemersma (17) suggested that the use of the lateral speed cue is an effect of driving experience. This finding was confirmed in a study by Blaauw et al. (14) who compared OCM predictions with field data of experienced and inexperienced drivers. The OCM predictions without lateral speed cue resulted in occlusion durations conforming to those of inexperienced drivers. This result is also in accordance with findings of Smiley et al. (18) who illustrated that inexperienced drivers do not only use the lateral position cue, but also yaw rate and both acceleration cues.

Both TLC and OCM analyses utilize vehicle characteristics as basic elements for predictions. Hence, it seems reasonable to apply these supervision models for the evaluation of vehicle handling properties. The models, in particular, are valuable with regard to the time-related analysis of the driver's attention needed for the driving task as affected by vehicle handling characteristics (i.e., understeering-oversteering) and vehicle dimensions.

In general, the models are applicable to such topics as the effect of various types of road markings on driving performance, the effects of driving practice, the effects of various types of road design, advice speeds, vehicle design, and the evaluation of steering properties.

REFERENCES

Impact of Drunk Driving Legislation in the State of Alabama

SAEED MAGHSOODLOO and DAVID B. BROWN

ABSTRACT

On May 19, 1980, a major revision in the Alabama driving-under-the-influence (DUI) laws went into effect, which gave judges greater discretion in sentencing. In this paper, the period before the revision of the law, in which a DUI conviction automatically resulted in revocation of the driver's license, is compared with the period after the revision. A significant increase was found in the number of DUI convictions of the after period, showing that the new law was being observed. This was accompanied by significant reductions in the number of DUI citations reduced to reckless driving, the proportion acquitted and/or dismissed, and the proportion of revocations. The law required court referral to an education program on the first offense, and these referrals significantly increased in the after period. However, the corresponding change in accidents was not favorable because there was a significant increase in the proportion of alcohol-related accidents in the after period.

On May 19, 1980, a major revision in the Alabama driving-under-the-influence (DUI) laws went into effect, which gave judges greater discretion in sentencing. The basic change in the law would appear to weaken its effectiveness in that the former mandatory revocation provision was removed. The former law stated that "The director of public safety shall forthwith revoke the license of any driver upon receiving a record of such driver's conviction of...driving a motor vehicle...while intoxicated." This provision was modified to read as follows:

The director of public safety shall forthwith revoke the license of any driver upon receiving a record of such driver's conviction of...driving a motor vehicle...while under the influence of intoxicating liquor; providing, however, that on a first conviction such revocation shall take place only when ordered by the court rendering such conviction.

In addition to these changes, first-time offenders were required to complete a DUI court-referral educational program approved by the State Administrative Office of Courts. In addition, the law specifically states that charges cannot be reduced to reckless driving or any other offense. (The consistent use of either of the terms "DWI" or "DUI" throughout this paper would be technically incorrect because Alabama used DWI before the law change and DUI after. However, in the remainder of this paper, DUI will be used.)

Although this change might be considered a weakening of the punitive measures related to DUI, the previous circumvention of the mandatory revocation by a large number of judges in Alabama made conviction of DUI on the first offense unlikely. The resulting inaccuracy in the records made recidivism impossible to measure and, thus, multiple offenders were not being consistently punished. In fact, under the situation prior to May 1980, most offenders were