ANALYSIS OF DYNAMIC MESSAGE SIGNS IMPACT ON DRIVER'S BEHAVIOR USING A DRIVING SIMULATOR

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ABSTRACT
Conducting field observations are challenging and resource intensive especially when examining driver behavior. In order to overcome this obstacle, the use of driving simulators is increasing. This study uses field observations, driving simulator, and a subjective survey to quantify the impact of dynamic message signs (DMS) on driver behavior and traffic flow under various scenarios and different traffic conditions. Field observation was carried out by capturing drive through videos, and extracting the speed data from the DMS sensors. Field evaluation verified the accuracy of the messages shown on DMS upstream of the work zone. Preliminary results from field observation indicates that DMS is effective in reducing congestion and reducing delay by providing real time information to drivers of a potential hazardous location.

Virtual scenarios for the driving simulator were modeled and simulated to assess the driver behavior. The factors considered in the design of the experiment are age group, gender, education level and the displayed message. The results of the paper can provide useful insights for transportation agencies in employing DMS for traffic control, operation and management of work zones. Further experiments will be carried out utilizing the driving simulator in the Engineering Research Lab at the Missouri University of Science and Technology.

1. INTRODUCTION
Work zones pose a significant risk to both workers and drivers. The use of innovative systems such as dynamic message technologies can play an important role in decreasing the societal cost of work zone crashes. Dynamic message signs (DMS) provide drivers with real time information of the occurrences in the work zone and also aims to harmonize the speed in the highway before and after the work zone (Dudek, C. L. 1997). DMS is an electronic traffic sign often used on roadways to give travelers real time information about traffic congestion, accidents, incidents, work zones, special events, or speed limits on a specific highway segment (see Figure 1). The basic premise for the deployment of these systems is to provide the traveling public with information regarding the status of the traffic or safety hazards (i.e., slowing/stopped traffic conditions) through the work zone. By providing this type of information, drivers are able to better control their vehicles or adapt to conditions, by taking alternate routes if needed. These systems also help reduce the frustration levels experienced by drivers caught in work zone traffic by providing information that will help the driver understand what lies ahead (Dixon et al., 2005)

Various studies have been conducted to evaluate the performance of DMS; however, most of the studies have surveyed departments of transportation and analyzed their response about the effectiveness of DMS (Bonsall and Merrall,1996; Ullman et al, 2005; Wang et al, 2007; Hardy et al, 2006). Some researchers also studied the effectiveness of DMS messages through evaluating various types of messages and signs (Dudek et al, 2000; Ullman et al, 2005; Hardy et al, 2006; Pareja, 2007). Researches have also studied the influence of queue/speed detection and alert systems (McCoy, 2000; Zwahlen and Russ, 2002; Tooley et al. 2002; Tudor et al. 2003; McCoy and Pesti 2002). DMS are also used in conjunction with other media to communicate traffic conditions, general information, and recommended diversion strategies to motorists. A study used loop detector data to estimate diversion rates attributable to advisory messages placed on DMS, as well as travel time savings and safety impacts (Schroeder and Demetsky, 2011). It was found that diversion is minimal when DMS messages are not clear to understand or a distant alternate route is the only option. Behavioral studies have also been conducted using real traffic system, on a test track, or in a driving simulator (Pham, M., de Mouzon et al, 2008; Chatterjee, K. et al, 2002). The inclusion of a driving simulator provides the capability to perform experiments on the driver in concern. Test tracks offer a safer environment and the
possibility of giving test drivers similar conditions and thereby decreasing the statistical uncertainty. However, test tracks lack realism and it can be hard to evaluate the validity of the results. Driving simulators on the other hand offer a realistic environment in which test conditions can be controlled and varied in a safe way (Olstam and Espie, 2007).

2. DATA COLLECTION AND METHODOLOGY

A subjective survey was conducted at a gas station located at an exit on I-44 near Waynesville, Missouri in a work zone with DMS. Figure 2 shows the demographic information of the 101 drivers that participated in the field survey. The survey gathered drivers’ demographic and trip information, and assessed drivers’ perception of the DMS characteristics such as legibility, clarity, reliability, etc. and the effects of DMS on delay, highway safety, and driving experience. The drivers ranked the effect of DMS on the various traffic flow characteristics, safety performances or general features of the displayed messages. The participants ranked on a scale of 1 to 5, 1 being the worst condition, and 5 being the best condition. The responses to these questions were analyzed to analyze how effective the DMS were from the viewpoint of the travelers.

Figure 2. Demographic information of the field survey

Also, field data (vehicle speeds) were collected at four sensor locations on I-44 (Figure 3). I-44 reconstruction project consisted of two stages. In this study, stage 2 of construction on I-44 westbound of will be simulated and used for the purpose of evaluation.

Figure 3. DMSs installed in the westbound direction of I-44 reconstruction project- Stage 2

Four sensors 9805, 9804, 9803, and 9802, were located at mile markers 164.2, 162.7, 159.6, and 161.9, respectively. DMS with different messages were displayed based on the level of traffic congestion in a cross-over work zone located after the DMS. Westbound lanes were fully closed and traffic was crossed over to eastbound lanes i.e., Head-to-head traffic in the eastbound lanes.

Table 1 shows the displayed message in each DMS based on the average speed at the work zone taper determined by a radar sensor. Each message included two phases that was flashing with a 1-second display time. Each phase showed half of the complete message in three lines. Phase one (top) and two (bottom) of the first type of message shown on DMS in I-44 reconstruction project displayed on two different DMS. Figure 4 show the two phases of the first type of message displayed one of the DMSs in the westbound direction of the I-44 reconstruction project.

Table 1. Displayed messages on DMS based on the level of congestion at the work zone taper

<table>
<thead>
<tr>
<th>Default (Message A)</th>
<th>Message B</th>
<th>Message C</th>
<th>Message D</th>
</tr>
</thead>
<tbody>
<tr>
<td>S &lt; 70 mph</td>
<td>S &lt; 50 mph</td>
<td>S &lt; 20 mph</td>
<td>S &lt; 5 mph</td>
</tr>
<tr>
<td>S &gt;= 50 mph</td>
<td>S &gt;= 20 mph</td>
<td>S &gt;= 5 mph</td>
<td></td>
</tr>
<tr>
<td>CAUTION WORKZONE AHEAD</td>
<td>SPEED AHEAD</td>
<td>PREPARE TO STOP</td>
<td>PREPARE TO STOP</td>
</tr>
<tr>
<td>XX MPH</td>
<td>XX MIN TO END OF WZ</td>
<td>XX MIN TO END OF WZ</td>
<td>STOPPED TRAFFIC AHEAD</td>
</tr>
</tbody>
</table>

| REDUCE SPEED AHEAD | XX MIN TO END OF WZ | XX MIN TO END OF WZ | STOPPED TRAFFIC AHEAD |

One-minute aggregated speed data were recorded by the radar speed sensors and were extracted from the database. Also, the content of the DMSs (displayed messages) during the project was extracted from the database for each day. Time-speed graphs were generated to determine the peak hours during each day of the project. Time-space diagrams (Figure 5) were generated for the peak hours and compared with the displayed messages shown during the same period to verify the accuracy of the DMS algorithm.
2.1 SIMULATOR EXPERIMENT

Figure 6 show the driving simulator located at the Engineering Research Laboratory, Missouri S&T which uses three LCD projectors, each having 3,000 lumens and controlled by a PC. The driving simulator is provided by the Ford Motor Company. Field data were used to validate results of speed variation attained from the simulator study of the same environment. Error! Reference source not found. shows the driving simulator. The virtual environment is displayed on a 6.5’x25’ screen.

2.2 Driving Simulator Setup

This simulator is a fixed-base Ford Ranger pick-up equipped with, a projection screen, and networked computers with Ethernet connection different sensors. The driving cabin is instrumented with optical encoders for measuring the input of the steering wheel, the gas pedal, and the brake pedal (speed average, speed variance, 85th percentile speed, acceleration/deceleration, lane position and movement, headway distance, etc). The projection screen has an arc angle of 54.6°, an arc width of 25 feet, and a height of 6.6 feet. The field of view is around 120°. The resolution of the visual scene generated by the master computer is 1024x768 pixels, the slave computers are 800x1200 pixels, and the refresh rate is 30 to 60 Hertz depending on the scene complexity. The driving simulator is also equipped with a system that replicates the sound of an engine. A more detailed description of the system structure, projection system, and the data acquisition process can be found in Wang et al. (2006).

The current driving simulator setup includes the latest Logitech G-27 steering wheel with in-built force feedback. The simulator also now can be controlled by one master computer. Data is collected from the control Panel of the G-27 steering wheel. The control panel of the steering wheel has been disassembled and integrated with the steering column and the chassis of the Ford ranger pickup truck. The current upgraded system has enough video outputs to run the entire system across six displays.

The subject vehicle was modeled and various scenarios of virtual environment were developed with DMS replicating the real world environment upstream of the work zone (Figure 6 and Figure 7). The scenarios were supplemented by GIS data in order to terrain map the highway to obtain accurate data of the work zone scenario, including work zone setup, placement of signs, the road geometry including the horizontal alignment, the vertical profile, the roadside elements of the work zone activity area and the advance warning section.
Blender 3D is being used to model the roads according to specifications of the Missouri Department of Transportation. Modeling of the vehicles and roadway was first carried out for each of the environment and then were appended to create a single environment. Dynamics were defined for the rigid bodies, dynamic bodies and static bodies. The virtual work-zone was modeled in Blender 3D (see Figure 8). The road signs, the trees were defined as a rigid body. The physics for these bodies was developed using the python script. Open source gaming simulation module, TORCS (Wymann), was used to import and test the scenarios that were modeled and rendered in Blender-3D. To replicate the roadway profile, piecewise modeling of the interstate was carried out. The curves and gradients as well as the terrain were designed according to the field data obtained by a video and terrain mapping software.

4. PRELIMINARY RESULTS

The field survey responses were examined using the spread sheets and graphs to subjectively evaluate the performance of DMS. Figure 9 presents results of the subjective evaluation of the effects of DMS on traffic flow characteristics. It can be observed that about half of the drivers were neutral about the effects of DMS on congestion, delay, and the chance of crash occurrence. By a general look at the Figure 9 a bell shaped graph (normal distribution) can be imagined that has the most responses in the neutral point. From these responses it might be concluded that drivers do not see the DMSs efficient in improving traffic flow characteristics.

Figure 8. Static and rigid bodies modeled in Blender 3D

Figure 9. Field subjective evaluation of the effects of DMS on traffic characteristics

Figure 10 presents the results of the field survey on the characteristics of the displayed messages. It can be observed that the majority of drivers perceive the information presented in the DMSs to be useful, legible, understandable, and reliable. Most of the drivers saw the message text size and length as appropriate (not too small/long, not too large/short). These results show that the message characteristics were favorable to the drivers.

Figure 11 shows the results of the survey on the effects of DMS on driving behavior. It can be observed that driving speed and lane changing behavior of drivers were affected as a result of DMS messages. Majority of surveyed drivers had a better driving experience with the real time DMS information presented to them and highly recommended to utilize the DMSs on the highway.
Figure 10. Field subjective evaluation of the displayed message characteristics

The time-space diagrams of the speed data from the radar sensors were generated to check the accuracy of the messages shown on DMSs. Figure 12 shows an example of the time-space diagram for the study of the whole peak period.

Figure 13 presents half hour of the peak period with the displayed messages on the time-space diagram. The labels on the graph represent the message displayed to the corresponding time. The messages displayed were verified by the algorithm of the DMS for the corresponding speed. The accuracy of the messages according to the algorithm was verified by the diagrams.

Figure 11 Survey result of the effects of DMS on driving behavior
5. DESIGN OF EXPERIMENT

Drivers will be recruited for the experiment to evaluate the effects of DMS on their behavior, consisting speed and their reaction messages displayed on the DMS. Considering three age groups, two genders, and four education levels (factors) for the experiment we will have \((3 \times 2 \times 4)\) twenty four treatment combinations for each message displayed (Figure 14). Young drivers (aged 17 to 40), middle-age drivers (41 to 60) and older drivers (61+) will be recruited. As the budget is limited, we plan to use CE211 (Transportation Engineering) students aged mostly between 18 and 25 from Missouri S&T. Similarly, professors and staff on campus will be recruited to study the behavior of middle-age drivers, and seniors, retired professors. Other drivers from the housings for older people in Rolla will be used, if needed. A sample of 20-40 drivers will participate in the study for each of the three age categories. Further, we plan to evaluate the effects of different messages in terms of safety. Parameters such as driver reaction times, headway distance, etc. will be studied.

6. FUTURE RESEARCH

This section presents the future steps in this study. In order to quantitatively evaluate the effects of DMS on driver behavior, a driving simulator will be used to replicate a real world work zone. According to the design of experiment presented...
previously, drivers will travel through the virtual environment and their reactions and behavior will be recorded.

Potential participants will be surveyed using a pre-screening questionnaire and those who satisfy all the requirements will be recruited for the experiment. Pre-screening questionnaire consists of questions related to education level, health problems, possession of a valid driving license, motion sickness, and prior knowledge of the research project. Subjects failing to fulfill with of the requirements will not be further considered. After the initial screening, participants will be invited to the driving simulator laboratory for the experiment.

All participants will complete a survey before and after the driving simulator experiment. Participants will first be given a brief introduction to the experiment and advised to adhere to traffic laws as they would in real work zone. The participants will also be told that they could quit the experiment at any time in case of any discomfort.

7. CONCLUSIONS
This study has conducted a field evaluation, a subjective survey evaluation and the accuracy of the messages shown on DMS was verified. The preliminary results of the field survey evaluation indicates that DMS was effective in reducing congestion and reducing delay by providing real time information to drivers of a potential hazardous location.

Future work of the study aims to use a driving simulator to quantify the impact of dynamic message signs (DMS) on driver behavior and traffic flow under various scenarios and different traffic conditions. The study will determine the effects of the factors such as age group, gender, education level of drivers and the displayed messages on the effectiveness of DMS on travel behavior. The study provides useful insights for transportation agencies in employing DMS for traffic control, operation and management of work zones.

8. REFERENCES


