Evaluation of Dynamic Speed Display Board in Highway Work Zones

Final Report

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ABSTRACT

Dynamic Speed Display (DSD) technology is one of the most commonly used speed control strategies. The DSD includes a speed radar sensor to detect the approaching vehicle speed and a changeable display board to show the measured speed. In general, the DSD board is attached to a portable trailer with a regulatory speed limit sign placed above it. By doing this, drivers can be informed of their speed and relationship to the posted speed limit. It is generally assumed that drivers will reduce their speed if the display board shows their speeds exceed the posted speed limit. There were three primary objectives in this study:

1. Record and compare the speed characteristics with and without DSD,
2. Measure the effectiveness of the DSD in work zone speed management, and
3. Determine the traffic flow characteristics (volume, occupancy and speed) where the strategy is the most effective.

DSD technology was applied at the work zone on STH 29 at Hatley, Wisconsin to manage speed over the entire project period. No enforcement was deployed on this project. The field data showed that more than half of all drivers during peak hours and 20 percent of all drivers during off-peak hours traveled above the posted speed limit.

The long-term placement of DSD board had limited impact on the daytime speed: neither a significant reduction in average speed nor reduction in percentage of speeding drivers was observed. However, 14 percent less drivers exceeded the speed limit at night during the “after” period with the DSD when compared with the “before” period, which stressed the promise of using DSD in curbing work zone speeding.

It was clear that the nighttime vehicle mix had a higher percentage of trucks than daytime periods. As stated previously, nighttime speed was reduced with the DSD operation. It is reasonable to assume that the mixed impact of high truck percentage and DSD presence may have affected driver behavior (i.e., speed) in the work zone. The relationship between the speed reduction, the percentage of trucks and the DSD deserves further investigation in future evaluations.
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PROJECT BACKGROUND

Dynamic Speed Display (DSD) technology is one of the most commonly used speed control strategies. The DSD includes a speed radar sensor to detect the approaching vehicle speed and a changeable display board to show the measured speed. In general, the DSD board is attached to a portable trailer with a regulatory speed limit sign placed above it. By doing this, drivers can be informed of their speed and relationship to the posted speed limit. It is generally assumed that drivers will reduce their speed if the display board shows their speeds exceed the posted speed limit. Figure 1 illustrates the DSD board used at a work zone on STH 29 near Hatley, Wisconsin.

There were three primary objectives in this study:

1. Record and compare the speed characteristics with and without DSD in work zones,
2. Measure the effectiveness of the DSD in work zone speed management, and
3. Determine the traffic flow characteristics (volume, occupancy and speed) where the strategy is the most effective.

The 0.873 mile long construction zone in which the DSD was evaluated was located on STH 29 at Hatley, Wisconsin as shown in Figure 2. STH 29 is a four-lane divided highway with two 12-foot lanes in each direction. This construction project was designed to convert the existing at-grade intersection of STH 29 and CTH Y into an interchange, including the construction of a new bridge and the realignment of existing CTH Y. Partial lane closures were used as the traffic control strategy. Either the inside or outside 12-foot lane was closed at all times during the project. The speed limit in the work area was reduced from the posted 65 mph to 55 mph. Average daily traffic was approximately 12,850 vehicles per day (vpd) with approximately 18 percent truck traffic. During weekdays, construction workers were present from 6:00 AM to 6:00 PM and if needed, on Saturdays from 6:00 AM to 2:00 PM. More details about the construction zone can be found in the construction maps with the work zone code 1053-09-71 in the Wisconsin Department of Transportation (WisDOT) work zone tracking system.
Figure 1. Dynamic Speed Display Board at Hatley Work Zone
Figure 2. Work Zone Location
DATA COLLECTION

The University of Wisconsin Traffic Operations and Safety (TOPS) Laboratory designed the non-intrusive traffic data collection system in which Remote Traffic Microwave Sensors (RTMS) were used to collect the volume, occupancy and speed (VOS) data. The sensors were powered by battery with a solar power recharging unit allowing for extended periods of data collection. Data were stored at five-minute intervals in the Remote Traffic Counter (RTC) unit with 4 Mb capacities allowing up to seven months of 5-minute continuous data collection. Figure 3 shows a typical RTMS traffic data collection system. The field location where the RTMS was installed is shown in Figure 4. The sensor was placed on the post adjacent to travel lanes with required offset and height at work zone activity area. The quality of RTMS speed data was calibrated with a hand-held Lidar gun.

To measure the DSD effectiveness, speed data for before and after the DSD installation were needed. “Before” data were collected without the DSD in operation and “after” data were collected with the DSD in operation. Since the DSD board had been placed in the work zone before the DSD evaluation started, “after” data were collected earlier than “before” data. The data collection calendar is shown in Table 1. Both “before” and “after” data collection periods lasted for one week. The “after” period started on September 29 and ended on October 5, 2005. The “before” VOS data were collected from October 6 to October 13, 2005. According to the project manager field work log, the DSD was turned on accidentally during the “before” data collection due to the lack of communication among the construction crew. Therefore, the VOS data for these days were considered to be biased and were not included in this study.

Table 1. Data Collection Calendar

<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>Activates</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/29/2005</td>
<td>THU</td>
<td>Install RTMS and Start &quot;after&quot; data collection</td>
</tr>
<tr>
<td>9/30/2005</td>
<td>FRI</td>
<td>DSD was on</td>
</tr>
<tr>
<td>10/1/2005</td>
<td>SAT</td>
<td>DSD was on</td>
</tr>
<tr>
<td>10/2/2005</td>
<td>SUN</td>
<td>DSD was on</td>
</tr>
<tr>
<td>10/3/2005</td>
<td>MON</td>
<td>DSD was on and flaggers stopped traffic occasionally</td>
</tr>
<tr>
<td>10/4/2005</td>
<td>TUE</td>
<td>DSD was on</td>
</tr>
<tr>
<td>10/5/2005</td>
<td>WED</td>
<td>DSD was on</td>
</tr>
<tr>
<td></td>
<td></td>
<td>End &quot;after&quot; data collection and start &quot;before&quot; data collection</td>
</tr>
<tr>
<td>10/6/2005</td>
<td>THU</td>
<td>DSD was turn off after 7:00 AM</td>
</tr>
<tr>
<td>10/7/2005</td>
<td>FRI</td>
<td>DSD was accidentally turned on</td>
</tr>
<tr>
<td>10/8/2005</td>
<td>SAT</td>
<td>DSD was accidentally turned on</td>
</tr>
<tr>
<td>10/9/2005</td>
<td>SUN</td>
<td>DSD was accidentally turned on</td>
</tr>
<tr>
<td>10/10/2005</td>
<td>MON</td>
<td>DSD was accidentally turned on</td>
</tr>
<tr>
<td>10/11/2005</td>
<td>TUE</td>
<td>DSD was off</td>
</tr>
<tr>
<td>10/12/2005</td>
<td>WED</td>
<td>DSD was off</td>
</tr>
<tr>
<td>10/13/2005</td>
<td>THU</td>
<td>DSD was off till 12:00 PM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>End &quot;before&quot; data collection and uninstall RTMS</td>
</tr>
</tbody>
</table>
Figure 3. RTMS at the Free Flow Section
Figure 4. RTMS in the Work Zone

DATA ANALYSIS

After the field data collection was finished, the VOS data were downloaded on site. Traffic Reporter, one of the RTMS components, was used to retrieve data from the downloaded database files. Since traffic volume and vehicle mix affect operating speeds, volume data were present along with the speed data.

Volume Characteristics

As previously mentioned, because of the miscommunication among construction crew, the “before” data for Monday, Thursday, Friday, and weekends were not available. Only Tuesday and Wednesday’s speed data could be used to perform unbiased analysis. For comparison, “after” data of the same weekdays were selected.

The traffic volume patterns of “before” and “after” DSD installation for Tuesday and Wednesday are shown in Figure 5. In addition, the bold lines represent the average volumes of “before” and
“after” weekdays calculated on the basis of available data. The overlapped average lines demonstrate strong similarity in “before” and “after” volume. P value of T-test, 0.791, also suggests that there is no significant difference between the two sets of volume data at a 95 percent confidence level. Therefore, both visual inspection and statistic test show that the “before” and “after” speed data were collected under similar traffic volume conditions. Additionally, truck percentages throughout the day also show similarity in “before” and “after” periods. Table 2 shows that the highest percentage of truck traffic was found during nighttime hours from 2 am to 6 am. The average truck percentage during daytime was 16 percent and nighttime was 27 percent.

Due to the fact that traffic volume and visibility might impact drivers’ speed in the work zone, the data set for an entire day was split into three parts: peak hour, off-peak daytime, and off-peak nighttime. Volume distributions in Figure 5 suggest that the peak hour period occurs in the afternoon from 4 PM to 6 PM. Therefore, the speed data analysis in the following sections was performed for three time periods separately.

![Figure 5. Weekday Traffic Volume for “Before” and “After” Periods](image-url)
<table>
<thead>
<tr>
<th>Time (Hour)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicles</td>
<td>43</td>
<td>28</td>
<td>29</td>
<td>40</td>
<td>43</td>
<td>72</td>
<td>145</td>
<td>265</td>
<td>239</td>
<td>259</td>
<td>286</td>
<td>276.5</td>
</tr>
<tr>
<td>Trucks</td>
<td>7</td>
<td>10</td>
<td>12</td>
<td>19</td>
<td>25</td>
<td>30</td>
<td>40</td>
<td>44</td>
<td>45</td>
<td>63</td>
<td>69</td>
<td>67</td>
</tr>
<tr>
<td>Truck</td>
<td>15%</td>
<td>36%</td>
<td>41%</td>
<td>48%</td>
<td>58%</td>
<td>41%</td>
<td>27%</td>
<td>17%</td>
<td>19%</td>
<td>24%</td>
<td>24%</td>
<td>24%</td>
</tr>
<tr>
<td>Before</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicles</td>
<td>45</td>
<td>32</td>
<td>32</td>
<td>38</td>
<td>41</td>
<td>66</td>
<td>159</td>
<td>272</td>
<td>236</td>
<td>265</td>
<td>274</td>
<td>333</td>
</tr>
<tr>
<td>Trucks</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>20</td>
<td>22</td>
<td>29</td>
<td>40</td>
<td>43</td>
<td>50</td>
<td>55</td>
<td>56</td>
<td>66</td>
</tr>
<tr>
<td>Truck</td>
<td>22%</td>
<td>30%</td>
<td>38%</td>
<td>52%</td>
<td>54%</td>
<td>44%</td>
<td>25%</td>
<td>16%</td>
<td>21%</td>
<td>21%</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>After</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicles</td>
<td>296</td>
<td>335</td>
<td>394</td>
<td>560</td>
<td>546</td>
<td>518</td>
<td>296</td>
<td>220</td>
<td>164</td>
<td>127</td>
<td>84</td>
<td>90</td>
</tr>
<tr>
<td>Trucks</td>
<td>43</td>
<td>56</td>
<td>46</td>
<td>56</td>
<td>46</td>
<td>42</td>
<td>39</td>
<td>31</td>
<td>23</td>
<td>14</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Truck</td>
<td>15%</td>
<td>17%</td>
<td>12%</td>
<td>10%</td>
<td>8%</td>
<td>8%</td>
<td>13%</td>
<td>14%</td>
<td>14%</td>
<td>11%</td>
<td>15%</td>
<td>17%</td>
</tr>
<tr>
<td>After</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicles</td>
<td>314</td>
<td>331</td>
<td>412</td>
<td>534</td>
<td>561</td>
<td>461</td>
<td>327</td>
<td>203</td>
<td>151</td>
<td>125</td>
<td>91</td>
<td>83</td>
</tr>
<tr>
<td>Trucks</td>
<td>64</td>
<td>51</td>
<td>51</td>
<td>48</td>
<td>45</td>
<td>31</td>
<td>32</td>
<td>29</td>
<td>17</td>
<td>19</td>
<td>24</td>
<td>11</td>
</tr>
<tr>
<td>Truck</td>
<td>20%</td>
<td>15%</td>
<td>12%</td>
<td>9%</td>
<td>8%</td>
<td>7%</td>
<td>10%</td>
<td>14%</td>
<td>11%</td>
<td>15%</td>
<td>26%</td>
<td>13%</td>
</tr>
</tbody>
</table>
Speed Data Characteristics

Speed Profiles

Speed data were split into three parts to eliminate the possible impact of volume on speed, namely peak hour (4 PM – 6 PM), off-peak hour with workers’ presence (6 AM – 4 PM) and off-peak hour without workers’ presence (6 PM – 6 AM). The 5-minute raw data were averaged by 15-minute intervals and were used to exhibit the speed change trends throughout a day in the speed profiles shown in Figures 6 through 11. Figures 6 to 8 present speed profiles of three time periods for “before” Tuesday and “after” Tuesday. Similarly, Wednesday’s data were represented in Figures 9 to 11.

![Figure 6: Tuesday Peak Hour “Before” and “After” Comparison](image-url)
Figure 7: Tuesday Off-peak with worker presence “Before” and “After” Comparison

Figure 8: Tuesday Nighttime “Before” and “After” Comparison
Figure 9: Wednesday Peak Hour “Before” and “After” Comparison

Figure 10: Wednesday Off-peak with Worker Presence “Before” and “After” Comparison
Tuesday daytime off-peak speed was lower than peak hour speed in the work zone. This difference may be due to any of several variables including the difference in driver population. Commuters traveling during afternoon peak hours were familiar with the work zone and may consider 55 mph a safe speed. While drivers traveling during off-peak hours may not be familiar with the work zone; therefore, drove at a lower speed with caution when workers were present. Therefore, drivers did not further decrease speed in the work zone during the daytime off-peak because the speed already lowered than 55 mph. Only during nighttime conditions without work zone activities were speed changes significant.

The speed profiles on Wednesday demonstrate the relatively same patterns as Tuesday. The speed reduction in daytime is not conspicuous. During nighttime hours, speed was noticeably lower between 9 PM and 2 AM. Volume data in Table 2 shows that almost 30 percent of the nighttime vehicles were trucks. It can be assumed that truck’s constrained navigation by complex work zone configurations leads to lower average speed at night.

**Speed Descriptive Statistics**

The speed descriptive statistics including average (mean) speed, median speed, standard deviation, 85th percentile speed, frequency distribution for each speed bracket, and percentage of observations exceeding speed limit are illustrated in Table 3. Additionally, for comparison, the speed differences between “before” and “after” period were calculated and presented in the same table.
The average speeds in the work zone were 55.1 mph, 51.4 mph, and 54.9 mph for PM peak, daytime off-peak and nighttime during “before” period, respectively. Although the average speeds were equal to or below the 55 mph speed limit, about 54 percent (peak), 18 percent (daytime off-peak), and 58 percent (nighttime) of drivers exceeded the work zone speed limit.

DSD had marginal impact on daytime speed: during the “after” period, average speed for the peak period was 0.5 mph lower than the “before” period and the P-value, 0.44, shows that the speed reduction was not statistically significant at a 95% level of confidence. No reduction was observed for daytime off-peak. In addition, the percentage of vehicles exceeding speed limit increased 4 percent and 10 percent during peak hour and daytime off-peak, respectively.

On the contrary, the nighttime average speed during “after” period was 1 mph lower when compared with “before” period. This difference was statistically significant with a P-value of 0.0003. As shown in Table 3, there were 14 percent less drivers speeding in nighttime hours during the “after” period. More than half of all drivers traveled above the speed limit during the “before” period.

Figure 12 depicts the trends for the percentage of drivers exceeding the speed limit over a 24-hour “before” and “after” periods, supporting the fact that “after” period had less drivers speeding during nighttime hours. No similar decrease in the percentage of speeding drivers can be observed during daytime hours. In daytime hours, the percentage of speeding drivers was less than nighttime hours during both “before” and “after” periods.
### Table 3. Work Zone Before/After Weekday Speed

<table>
<thead>
<tr>
<th>Data Collection Period</th>
<th>Speed (mph)</th>
<th>Percentage of Vehicles in Speed Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Median</td>
</tr>
<tr>
<td>Daytime</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>55.1</td>
<td>55.0</td>
</tr>
<tr>
<td>After</td>
<td>54.5</td>
<td>55.0</td>
</tr>
<tr>
<td>Difference</td>
<td>-0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Nighttime</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>51.4</td>
<td>51.3</td>
</tr>
<tr>
<td>After</td>
<td>52.8</td>
<td>53.1</td>
</tr>
<tr>
<td>Difference</td>
<td>1.5</td>
<td>1.9</td>
</tr>
<tr>
<td>24-hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>54.9</td>
<td>55.0</td>
</tr>
<tr>
<td>After</td>
<td>53.8</td>
<td>53.8</td>
</tr>
<tr>
<td>Difference</td>
<td>-1.0</td>
<td>-1.3</td>
</tr>
</tbody>
</table>

Note: Bold numbers are the speed differences between “before” period and “after” periods.

![Figure 12: Hourly Percentage of Speed Exceeding Speed Limit](image-url)
FINDINGS AND DISCUSSIONS

DSD technology was applied at the work zone on STH 29 at Hatley, Wisconsin to manage speed over the entire project period. No enforcement was deployed on this project. The field data showed that more than half of all drivers during peak hours and 20 percent of all drivers during off-peak hours traveled above the posted speed limit.

The long-term placement of DSD board had limited impact on the daytime speed: neither a significant reduction in average speed nor reduction in percentage of speeding drivers was observed. However, 14 percent less drivers exceeded the speed limit at night during the “after” period with the DSD when compared with the “before” period, which stressed the promise of using DSD in curbing work zone speeding.

It was clear that the nighttime vehicle mix had a higher percentage of trucks than daytime periods. As stated previously, nighttime speed was reduced with the DSD operation. It is reasonable to assume that the mixed impact of high truck percentage and DSD presence may have affected driver behavior (i.e., speed) in the work zone. The relationship between the speed reduction, the percentage of trucks and the DSD deserves further investigation in future evaluations.
APPENDIX

1. Testing Differences between Two Volume Samples by paired t-test:

The 24 hours volume data for two days are grouped into 24 pairs by time.

H₀: There is no difference between two volume means
H₁: There is difference between two volume means

Test statistic:
\[ t = \frac{X_d}{s_d \sqrt{\frac{1}{n_d}}} \]

where: \( X_d \) = Average sample difference between each pair of observed volumes
\( s_d \) = Sample standard deviation of difference of paired volumes
\( n_d \) = Number of paired volumes

The \((1 - \alpha)100\%\) confidence interval for the mean difference is
\[ \frac{X_d}{\pm t_{\alpha/2}} \sqrt{\frac{s_d}{n_d}}. \]
When this confidence interval includes zero, null hypothesis can be accepted. Otherwise, null hypothesis will not be accepted.

2. Testing Differences between Two Speed Samples by t-test:

H₀: There is no difference between two speed means
H₁: There is difference between two speed means

Test statistic:
\[ t = \frac{(X_1 - X_2)}{\sqrt{s_p \left( \frac{1}{n_1} + \frac{1}{n_2} \right)}} \]

where: \( X_1, X_2 \) = Average sample means of two observed speed sets
\( n_1, n_2 \) = Number of paired volumes
\[ s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2} \]

The \((1 - \alpha)100\%\) confidence interval for the mean difference is
\[ (X_1 - X_2) \pm t_{\alpha/2} \sqrt{s_p \left( \frac{1}{n_1} + \frac{1}{n_2} \right)}. \]
When this confidence interval includes zero, null hypothesis can be accepted. Otherwise, null hypothesis will not be accepted.