SPEED REDUCTION EFFECTS OF CHANGEABLE MESSAGE SIGNS IN A CONSTRUCTION ZONE

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A Report of the findings of:
Investigation of speed control methods in work zones

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SPEED REDUCTION EFFECTS OF CHANGEABLE MESSAGE SIGNS IN A CONSTRUCTION ZONE

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STUDY TITLE:
"Investigation of Speed Control Methods in Work Zones"
Project IHR-014

This study evaluated the vehicular speed reduction effects of displaying speed limit and information messages on a changeable message sign (CMS) placed inside the work activity area in a work zone for a one lane closure on a rural interstate highway. It also examined the additional effects of using two CMS devices compared to one CMS. The following three experiments were conducted: (1) One CMS in advance of the work zone (Experiment 1), (2) One CMS inside the work activity area (Experiment 2), and (3) Two CMSs inside the work activity area (Experiment 3). Displaying speed limit and information messages on CMSs placed in the work activity area was effective in reducing the average speed and percentages of vehicles with excessive speeds. Comparing the results from Experiments 2 and 3 indicated that displaying the CMS messages reduced the speed of cars immediately after passing the CMS, but not at a point far from the CMS. Although trucks did not consistently reduce their speeds near the first CMS, trucks traveled at reduced speeds after passing the CMS. Cars and trucks reduced their speeds by as much as 5 and 4 mph, respectively, near the CMS. The speed reduction depended on the travel speed of the vehicles. Placing the CMS in the work activity area was more effective than putting it in advance of the work zone.

Work Zone, Traffic Control, Changeable Message Signs, Speed Reduction, Speed Limit, Speed Control

Unclassified

Unclassified
ACKNOWLEDGMENT AND DISCLAIMER

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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation or the Federal Highway Administration.
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INTRODUCTION

This study evaluated the speed reduction effects of using a changeable message sign (CMS) inside a work zone for displaying speed limit and information messages, and also computed the additional effects of using two CMSs devices compared to one CMS. The study also determined the immediate speed reduction effects of a CMS placed in advance of the work zone (WZ). For definition of areas within a work zone, one may refer to Lewis(1). The following three experiments were conducted:

1. One CMS in advance of the work zone (Experiment 1).
2. One CMS inside the work activity area (Experiment 2).
3. Two CMSs inside the work activity area (Experiment 3).

This report is a part of a study on speed control methods in work zones conducted for the Illinois Department of Transportation. Putting CMSs in work zones may have other benefits, such as increasing alertness of drivers, calling their attention to the work zone, etc., that were not considered in this study.

The data was collected on July 9-12, 1990, in a work zone located on I-57 near Mattoon, Illinois. The work zone was about 3.5 miles long. The construction crew was mainly working on two bridges (bridge deck repair). Other work zone activities involved shoulder improvements and minor repair works. The Illinois standard traffic control plan for one lane closure on rural interstate highways was used in this location. The standards are prepared based on the procedures of the Manual on Uniform Traffic Control Devices (MUTCD) (2). The layout of the construction zone and the signs used are schematically shown in Figure 1. The highway has two lanes per direction with one lane closed in each direction. The average daily traffic in this section of I-57 is 11,800 with 2,600 heavy commercial vehicles. The data reduction steps are discussed in Appendix A.

Previous Studies on CMSs

Changeable message signs have been effectively used to encourage and direct traffic to leave closed lanes before they approach the work zone (3-6). For guidelines on the use of changeable message signs one may refer to Dudek (7). When supplemental lane closure warning signs and variable message signs were placed before the taper, the percentage of vehicles in the closed lane was reduced from 22% to 11% at a location 0.1 miles before the taper (6). A specific diversion message proved to be more effective than a general diversion message (3).

Speed reduction effects of changeable message signs have not been fully investigated. Only a limited number of studies have evaluated the effects of a CMS at a certain point in work zones.
A study (6) reported that putting a CMS in advance of a work zone lane closure taper reduced the speed by 7.0-7.6 mph at a point 100 feet before the beginning of the taper. It should be noted that in the aforementioned study (6), the CMS and speed measuring station were both located in advance of the lane closure taper. Similarly, other studies (8, 9) found that placing a CMS in the advance warning area (before the work zone lane closure taper, if there was one) reduced the speed by 0-5 mph in the work zone. The reductions were 3-5 mph in rural freeways, 0-2 in urban freeways, and 3 mph in an undivided multi-lane urban arterial. It should be noted that in the aforementioned studies (8, 9), when there was a lane closure taper, the CMS and speed measuring station (Station 2 in their studies) were both in advance of the lane closure taper of the highway.

The previous studies did not look at the speed reduction effects of placing a CMS past the advance warning area (after the lane closure taper and within the reduced-lane section of the work zone), and did not measure the speeds in the activity area (e.g., between the work space and the end of the taper). It is important to note that in the advance warning area vehicles adjust their speeds to the work zone conditions and have not reached a "desired" speed level that they will be traveling at in the activity area. The previous studies also did not look at the speed reduction effects of CMSs on cars and trucks separately. This study was intended to look at the aspects that the previous studies did not look at.
METHODOLOGY

The methodology used for this study is commonly known as the before and after study with control group. The existing work zone (WZ) condition is considered to be the control group (CMS was placed in the work zone, but was not turned on). When one or two CMSs were turned on it was considered a treatment condition. Data were collected for both treatment and control conditions. Separate statistical analyses were performed for cars and trucks. All statistical analyses were performed using the personal computer version of Statistical Analysis System (SAS) software, PC-SAS Version 6.04, (10).

Two types of analyses were conducted:

1) Speed characteristics analysis.
2) Speed reduction analysis.

For the speed characteristics analysis, speed distribution and speeding problems were examined. For the speed reduction analysis, the net changes in speeds when the CMS was turned on compared to the control condition were studied.

Speed Characteristics Analysis

The minimum, mean, and maximum speed, standard deviation, frequency distribution, and percentage of vehicles exceeding a given speed level were determined. F-tests and t-tests were performed to compare speed variances and mean speeds, respectively. The two tests are briefly discussed below. A 95% confidence level is used when it is not stated otherwise.

For testing the hypothesis, for example, that the speed variance for cars was equal to that of trucks, an F-test was used. The calculated F-value is expressed as:

$$F = \frac{S_{cr}^2}{S_{tr}^2}$$

Where:

- $S_{cr}^2$ = Speed variance of cars.
- $S_{tr}^2$ = Speed variance of trucks.

For testing the hypothesis that, for example, the mean speed of cars was equal to the mean speed of trucks, a t-test was used. The t-value is computed from the following equation:
\[
t = \frac{\bar{U}_{cr} - \bar{U}_{tr}}{S_d}
\]

where:

\( \bar{U}_{cr} \) = The mean speed of cars.
\( \bar{U}_{tr} \) = The mean speed of trucks.
\( S_d \) = The standard deviation of the difference between mean speed of cars and trucks.

One assumption that was needed in order to use the t-test was that the speed data had to have a normal distribution. The data used in this study were for free flow vehicles and therefore did not necessarily have a normal distribution. However, the t-test was still viable because of its relative insensitivity to normal distributions (11). When the distributions of speeds were not the same (unequal variances), an approximate value of ‘t’ was used to reflect the difference in the shapes of the distributions (10).

**Speed Reduction Analysis**

In order to find out whether there were additional speed reductions due to turning the CMS on in the construction zone, the net speed reductions were computed. The net speed reduction at Station 2 was computed using the data from Station 1 as the control station. In other words, the speed difference between the treatment and control data at Station 1 was used as the expected value for the speed difference at Station 2 if the CMS was not in place.

A t-test with 95% confidence level was used to determine if the net reduction was statistically significant. The t-test was made by determining the net speed change from the following equation:

\[
\text{Net speed change at Station n} = (\bar{U}_{nt} - \bar{U}_{nc}) - (\bar{U}_{lt} - \bar{U}_{lc})
\]

Where:

\( \bar{U}_{lt} \) = The treatment mean speed at Station 1.
\( \bar{U}_{nt} \) = The treatment mean speed at Station n, n=2 or 3.
\( \bar{U}_{lc} \) = The mean speed for control data at Station 1.
\( \bar{U}_{nc} \) = The mean speed for control data at Station n, n=2 or 3.
SUMMARY OF EXPERIMENT 1 - ONE CMS IN ADVANCE OF WORK ZONE

Overview of Experiment 1

Experiment 1 was conducted to determine the immediate speed reduction effects of placing one CMS in advance of the work zone. The CMS was placed about 650 ft. before the "Road Construction 1 Mile" sign, and was outside of the traffic control zone. There was a distance of approximately 6100 ft. from the CMS to the beginning of the lane closure taper. Two alternating messages were displayed on the CMS. The messages were: "WORKERS AHEAD" and "SPEED LIMIT 45 MPH." Each message was displayed for three seconds. A summary of the findings from this experiment is presented here, but detailed discussions are given in Appendix B.

Data were collected at Station 1A and Station 2A. The location of the speed stations and the CMS are shown in Figure B.1. At Station 1A, the drivers could not see the CMS, but immediately after passing it the drivers saw the CMS. Station 1A was 3600 ft. before the CMS, but Station 2A was 1100 ft. after the CMS. The data was collected for free flow traffic on the outside lane. A vehicle was considered to be in free flow condition if its time headway was greater than 5 seconds. The speed limit on the highway was 55 mph for trucks and 65 mph for cars. However, in the work zone, the speed limit was 45 mph for all vehicles.

Findings For Experiment 1

The results of data analysis for Experiment 1 indicated that displaying the speed and information messages on the CMS caused a net speed reduction of 2.8 mph on cars and 1.4 mph on trucks at Station 2A. These reductions are statistically significant, although the reduction for trucks may not be considered practically significant. Furthermore, the messages reduced the number of cars exceeding the speed limit by 20%.
EXPERIMENT 2 - ONE CMS INSIDE THE WORK ZONE

Description of Experiment 2

One CMS was placed in the one-lane section of the WZ about 1/2 mile past the beginning of the lane closure taper. The outside traveled lane was closed and the CMS was placed on the shoulder. The CMS displayed the following alternating messages: "WORKERS AHEAD" and "SPEED LIMIT 45 MPH." Each message was displayed for two seconds.

The flashing lights on the speed limit signs were on during data collection to indicate that the work zone speed limit was 45 mph. Construction crews were working on the bridge over Route 16 and the bridge at milepost 187. New Jersey barriers were used over the bridges to delineate the traveled lane from the work space.

Data Collection for Experiment 2

Data were collected on the southbound lane of I-57 at three locations. All three locations were inside of the work zone. The first location, referred to as Station 1, was about 2300 ft. past the beginning of the lane closure taper. The second location, Station 2, was approximately 1700 ft. from Station 1, and 900 ft. from the first CMS. The third location, Station 3, was located over two miles past Station 2, and 1000 ft. past the second CMS. Figure 2 shows the relative location of the data collection stations for Experiment 2.

Data for Experiment 2 were collected on Tuesday, July 10, 1990, from 1:30 pm to 3:00 pm. Control data was collected on Thursday, July 12, 1990, from 10:00 am to 12:00 noon. The weather was hot and the pavement was dry during the data collection period. The data was collected on the inside lane using traffic counters with road tubes.

Speed Characteristics

In the following sections the speed characteristics for cars and trucks in control and treatment data for Experiment 2 are discussed. A summary of speed statistics is given in Table 1. In general, cars traveled faster than trucks, even though the speed limit was the same for both types of vehicles (see Figure 3). The car drivers traveled 9 to 13 mph faster than the speed limit and over 90% of them exceeded the speed limit. The truck drivers were traveling 5 to 8 mph faster than the speed limit and over 75% of them traveled faster than the speed limit. The speed variances of cars were higher than those of trucks for the most part, indicating that cars traveled at a wider range of speeds than trucks. Speed frequency distributions at Stations 1, 2, and 3 are shown in Figures 4 through 9.
Figure 2. Locations of Speed Stations and Changeable Message Sign (CMS)
Inside Work Zone on I-57

# Indicates CMS used in 1 CMS Experiment (Experiment 2)
* Indicates CMS used in 2 CMS Experiment (Experiment 3)
Table 1. Speed Statistics for Experiment 2
(1 CMS Inside of Work Zone)

<table>
<thead>
<tr>
<th></th>
<th>Control Data</th>
<th>1 CMS inside of Work Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Station 1</td>
<td>Station 2</td>
</tr>
<tr>
<td></td>
<td>cars</td>
<td>trucks</td>
</tr>
<tr>
<td>No. of Veh</td>
<td>279</td>
<td>105</td>
</tr>
<tr>
<td>Mean speed</td>
<td>55.09</td>
<td>49.72</td>
</tr>
<tr>
<td>Min speed</td>
<td>38</td>
<td>40</td>
</tr>
<tr>
<td>Max speed</td>
<td>74</td>
<td>63</td>
</tr>
<tr>
<td>Standard</td>
<td>7.20</td>
<td>5.46</td>
</tr>
<tr>
<td>deviation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent</td>
<td>92.5</td>
<td>75.2</td>
</tr>
<tr>
<td>exceeding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>speed limit</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3. Average Speed of Vehicles For 1 CMS inside Work Zone (Exp. 2)

Average Speed (mph)

Station

<table>
<thead>
<tr>
<th>Car Control</th>
<th>Car Treatment</th>
<th>Truck Control</th>
<th>Truck Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>me</td>
<td>me</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>me</td>
<td>me</td>
<td></td>
</tr>
</tbody>
</table>

Speed Characteristics of Cars in Control Data

The speed distribution at Station 2 had the widest range (40 mph) and the highest standard deviation. The average speed of cars was 10 to 13 mph higher than the speed limit of 45 mph. The percentages of cars exceeding the speed limit were 93%, 97%, and 99% at Stations 1, 2, and 3, respectively. About 42% of cars at Station 1, 58% at Station 2, and 72% at Station 3 traveled faster than 55 mph. Seven to 12% of cars traveled faster than 65 mph. The percentage of cars exceeding a given speed level is shown in Figure 10.

Speed Characteristics of Trucks in Control Data

The speed distributions for trucks did not appear to be bell-shaped, indicating that trucks did not follow a modal speed. The maximum speed range for trucks was 23 mph. The average speeds of trucks were 5 to 8 mph higher than the speed limit. The percentage of trucks exceeding a given speed level is shown in Figure 11. The percentages of trucks exceeding the speed limit were about 75%, 92% and 96% at Stations 1, 2, and 3, respectively. The percentages of
Figure 4. Speed Frequency at Station 1 for Control Data (Exp. 2)

Figure 5. Speed Frequency at Station 2 for 1 CMS Inside Work Zone (Exp. 2)
Figure 6. Speed Frequency at Station 2 for Control Data (Exp. 2)

Percentage of Observations

![Speed Frequency at Station 2 for Control Data (Exp. 2)](#)

Figure 7. Speed Frequency at Station 2 For 1 CMS Inside Work Zone (Exp. 2)

Percentage of Observations

![Speed Frequency at Station 2 For 1 CMS Inside Work Zone (Exp. 2)](#)
Figure 8. Speed Frequency at Station 3 for Control Data (Exp. 2)

Figure 9. Speed Frequency at Station 3 for 1 CMS Inside Work Zone (Exp. 2)
Figure 10. Cars Exceeding Given Speed For Control Data (Exp. 2)

Figure 11. Trucks Exceeding Given Speed For Control Data (Exp. 2)
trucks exceeding 55 mph were 14%, 16%, and 28% at Stations 1, 2, and 3, respectively. No truck traveled faster than 65 mph.

Comparison of Speed of Cars to Speed of Trucks in Control Data

The average speed of cars was higher than the average speed of trucks at all three stations, although the speed limit was the same for both vehicle types. The results of t-tests indicated that at all stations the mean speeds of cars were significantly higher than those of trucks (see Table 2). Similarly, the speed distributions of cars and trucks were not equal. The results of F-tests indicated that at all three stations there were significant differences between speed variances of cars and trucks. Cars exceeded the speed limit more than trucks.

Table 2.
Comparison of Speeds of Cars and Trucks for Experiment 2
(one CMS Inside Work Zone)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Station</th>
<th>Variances of Speed</th>
<th>Mean Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Prob&gt;F'</td>
<td>Inference</td>
</tr>
<tr>
<td>Control</td>
<td>1</td>
<td>0.0013</td>
<td>unequal</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.0003</td>
<td>unequal</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.0222</td>
<td>unequal</td>
</tr>
<tr>
<td>CMS ON</td>
<td>1</td>
<td>0.0262</td>
<td>unequal</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.3037</td>
<td>equal</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.0476</td>
<td>unequal</td>
</tr>
</tbody>
</table>

Speed Characteristics of Cars With 1 CMS in Work Zone

On the average, cars traveled 9 to 10 mph faster than the speed limit. The percentages of cars exceeding a given speed level are given in Figure 12. The percentages of cars exceeding the speed limit were 91%, 95%, and 96% at Stations 1, 2 and 3, respectively. About 40 to 47 percent of cars traveled faster than 55 mph, and about 5 to 9 percent faster than 65 mph.
Speed Characteristics of Trucks With 1 CMS in Work Zone

Trucks had the highest speed range (28 mph) at Station 1, but traveled at a more uniform speed at Station 3 than the other two stations. The percentages of trucks exceeding the speed limit were about 86%, 85% and 88% at Stations 1, 2, and 3, respectively. The percentage of trucks with 55 mph speeds or higher was about 20% at Stations 1 and 3, but 32% at Station 2. The percentages of trucks exceeding a given speed level are given in Figure 13. The data showed that trucks did not travel faster than 65 mph in the work zone.

Comparison of Speed of Cars to Trucks With 1 CMS In Work Zone

The average speed for cars was 2-4 mph higher than that of trucks. The speed variances of cars and trucks were equal only at Station 2. Cars traveled faster than trucks at Stations 1 and 3, but at Station 2 there was not a significant speed difference (see Table 2). Percentages of cars exceeding a given speed limit were higher than those of trucks.

Net Speed Reduction

The net speed reductions for cars and trucks at Station 2 and 3 were computed using the procedure described in the Methodology section. The net reductions are summarized in Table 3.

Net Speed Reduction for Cars

The net speed reduction for cars at Station 2 was 1.67 mph. The result of a t-test indicated that the net reduction is significant. This indicates that placing one CMS inside of the work zone caused about 1.7 mph additional speed reduction on cars. The net speed reduction for cars at Station 3 was not statistically significant. This means that putting 1 CMS inside the work zone did not cause significant additional speed reduction on cars at Station 3. Therefore, using one CMS was effective in reducing speed of cars by about 1.7 mph near the CMS, but not effective far from the CMS.

Net Speed Reduction for Trucks

The net speed reduction for trucks at Station 2 was equal to -0.47 mph. The result of t-test shows that this difference is not statistically significant. Thus, placing one CMS inside the work zone was not effective in reducing the average speed of trucks at
Figure 12. Cars Exceeding Given Speed For 1 CMS Inside Work Zone (Exp. 2)

Figure 13. Trucks Exceeding Given Speed For 1 CMS Inside Work Zone (Exp. 2)
Station 2. However, the net speed reduction for trucks at Station 3 was equal to 3.67 mph, and this difference is statistically significant. Therefore, using one CMS was not effective in reducing the speed of trucks near the CMS, but was effective far from the CMS. Trucks traveled about 3.7 mph slower when the CMS was turned on than when it was off.

Table 3.

Net Speed Reductions (mph) When One CMS Was Inside Work Zone

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Between Stations 1 and 2</th>
<th>Between Stations 1 and 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Net Speed Reduction</td>
<td>T-test Inference</td>
</tr>
<tr>
<td>Cars</td>
<td>1.67</td>
<td>significant</td>
</tr>
<tr>
<td>Trucks</td>
<td>-0.47</td>
<td>not significant</td>
</tr>
</tbody>
</table>

Conclusions For Experiment 2

The results of Experiment 2 indicated that displaying the speed limit and information messages on the CMS was effective in reducing the average speed of cars an additional 1.7 mph at a point near the CMS (about 1000 ft. from it). However, it was not effective at a point far from the CMS (about 2 miles). Trucks, on the other hand, showed an opposite trend. Displaying the messages on the CMS was not effective in reducing speed of trucks near the CMS, but far from the CMS it produced a 3.7 mph additional speed reduction. Thus, the data indicates that cars reacted by slowing down near the CMS, but the effect was not sustained at a point far from the CMS. However, trucks did not reduce their speeds immediately near the CMS, but traveled at a reduced speed far from the CMS. In general, the percentages of vehicles with excessive speeds decreased, except for trucks at Station 2, when the CMS was displaying the messages.
EXPERIMENT 3 - TWO CMSs INSIDE OF THE WORK ZONE

Description of Experiment 3

For Experiment 3, two CMSs were placed within the same construction zone. One CMS was placed at the same location as in Experiment 2 (about 1/2 mile past the beginning of lane closure taper) and the second CMS was located about 2 miles further down from the first CMS. The second CMS was not visible from the first CMS location. Data was collected at three stations as shown previously in Figure 2. The CMS displayed the following two alternating messages: "WORKERS AHEAD" and "SPEED LIMIT 45 MPH." Each message was displayed for 2 seconds.

Similarly to Experiment 2, the flashing lights on the speed limit signs were on during data collection. Construction crews were working on the bridge over Route 16 and the bridge at milepost 187. New Jersey barriers were used over the bridges to delineate the traveled lane from the work space.

Data Collection for Experiment 3

Data was collected on the southbound lane of I-57 at the same three stations used in Experiment 2. The locations of data collection stations and CMS devices in Experiment 3 are shown in Figure 2. Station 1 was approximately 2300 ft. past the beginning of the lane closure taper. Station 2 was located approximately 1700 ft. past Station 1 and 900 ft. from the first CMS. Station 3 was located over two miles from Station 2 and 1000 ft. further down from the second CMS. Treatment data was collected on Thursday, July 12, 1990, from 1:00 pm to 3:00 pm. Control data was collected on the same day, from 10:00 am to 12:00 noon. It was a typical hot and sunny day with dry pavement. The data was collected on the inside lane using traffic counters with road tubes.

Speed Characteristics

In the following sections the speed characteristics for cars and trucks for Experiment 3 are discussed. A summary of speed statistics for each station is given in Table 4. Since the control data for Experiment 3 is the same as that for Experiment 2, the speed characteristics for only 2 CMS Treatment are discussed in this section. The speed characteristics for the control data for this experiment were discussed in the Experiment 2 section.

Cars traveled 8-10 mph faster the speed limit and over 91% of car drivers had speeds greater than the speed limit. Truck drivers drove about 7 mph faster than the speed limit and over 91% of them exceeded the speed limit at Stations 1 and 3. At Station 2, the average speed of trucks was 4 mph over the speed limit and 74% were
Table 4. Speed Statistics for Experiment 3
(2 CMS Inside of Work Zone)

<table>
<thead>
<tr>
<th></th>
<th>Control Data</th>
<th>2 CMS inside of Work Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Station 1</td>
<td>Station 2</td>
</tr>
<tr>
<td></td>
<td>cars</td>
<td>trucks</td>
</tr>
<tr>
<td>No. of Veh</td>
<td>279</td>
<td>105</td>
</tr>
<tr>
<td>Mean speed</td>
<td>55.09</td>
<td>49.72</td>
</tr>
<tr>
<td>Min speed</td>
<td>38</td>
<td>40</td>
</tr>
<tr>
<td>Max speed</td>
<td>74</td>
<td>63</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>7.20</td>
<td>5.46</td>
</tr>
<tr>
<td>Percent exceeding speed limit</td>
<td>92.5</td>
<td>75.2</td>
</tr>
</tbody>
</table>
speeding. The average speed for cars was 0-4 mph higher than that of the trucks as shown in Figure 14. Statistical tests were made to compare the mean speed and speed variance of cars to those of trucks. At Stations 1 and 2, mean speeds of trucks were significantly lower than those of cars, but at Station 3 they were almost equal. Similar results were obtained for the speed variances. The speed frequency distributions for Stations 1, 2 and 3 are shown in Figures 15 through 17.

**Speed Characteristics of Cars With 2 CMSs in WZ**

The speed distributions for Stations 1 and 2 are more dispersed than that of Station 3 as indicated by the larger standard deviations. The widest range of speed (36 mph) was at Stations 1 and 2. On the average, cars traveled 8 to 10 mph faster than the speed limit. The percentages of cars exceeding a given speed level are given in Figure 18. The percentages of cars exceeding the speed limit were 93%, 91%, and 95% at Stations 1, 2 and 3, respectively. About 30 to 45 percent of cars traveled faster than 55 mph, and a very small percentage went faster than 65 mph.

**Speed Characteristics of Trucks With 2 CMSs in WZ**

Trucks had a lower standard deviation at Station 3 than at the other two stations. The percentages of truck exceeding speed limit were about 91%, 74% and 93% at Stations 1, 2, and 3, respectively. The percentages of trucks with a 55 mph speed or higher were about 23% at Station 1, 10 % at Station 2, and 24% at Station 3 (see Figure 19). The data showed that trucks did not travel faster than 65 mph in the work zone.

**Comparison of Speed of Cars to Trucks With 2 CMSs in WZ**

The speed variance of cars were higher than those of trucks at Station 1 and 2, but was equal at Station 3. Cars traveled faster than trucks at Stations 1 and 2, but at Station 3 there was not a significant speed difference (see Table 5). Percentage of cars exceeding a given speed limit were higher than those of trucks.
Figure 14. Average Speed of Vehicles for 2 CMSs inside Work Zone (Exp. 3)

![Ave Speed (mph)]

Figure 15. Speed Frequency at Station 1 for 2 CMSs Inside Work Zone (Exp.3)

![Percentage of Observations]

car  trucks
Figure 16. Speed Frequency at Station 2 for 2 CMSs Inside Work Zone (Exp.3)

Figure 17. Speed Frequency at Station 3 for 2 CMSs Inside Work Zone (Exp.3)
Figure 18. Cars Exceeding Given Speed for 2 CMSs Inside Work Zone (Exp. 3)

Figure 19. Trucks Exceeding Given Speed for 2 CMSs Inside Work Zone (Exp. 3)
Table 5.
Comparison of Speeds of Cars and Trucks for Experiment 3
(Two CMSs Inside Work Zone)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Station</th>
<th>Variances of Speed</th>
<th>Mean Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Prob&gt;F'</td>
<td>Inference</td>
</tr>
<tr>
<td>Control</td>
<td>1</td>
<td>0.0013</td>
<td>unequal</td>
</tr>
<tr>
<td>Control</td>
<td>2</td>
<td>0.0003</td>
<td>unequal</td>
</tr>
<tr>
<td>Control</td>
<td>3</td>
<td>0.0222</td>
<td>unequal</td>
</tr>
<tr>
<td>CMS ON</td>
<td>1</td>
<td>0.0035</td>
<td>unequal</td>
</tr>
<tr>
<td>CMS ON</td>
<td>2</td>
<td>0.0078</td>
<td>unequal</td>
</tr>
<tr>
<td>CMS ON</td>
<td>3</td>
<td>0.3562</td>
<td>equal</td>
</tr>
</tbody>
</table>

Net Speed Reduction

The net speed reduction for cars and trucks at Stations 2 and 3 were computed using the procedure described in the Methodology section. The net reductions for Experiment 3 are summarized in Table 6.

Net Speed Reduction for Cars

Cars had a net speed decrease of 4.61 mph at Station 2 and 4.70 mph at Station 3. These reductions were significant, and indicate that because of the CMSs the average speed of cars was additionally reduced by about 5 mph. The first CMS was effective in reducing the speed of cars (net reduction) by about 5 mph near the first CMS. The second CMS helped to maintain that speed reduction at Station 3. Thus, it can be concluded that when CMS devices were turned on the cars traveled at lower speeds than when they were turned off.

Net Speed Reduction for Trucks

The net speed reduction for trucks at Station 2 was equal to 3.68 mph. This difference is statistically significant. Thus, the first CMS caused an additional speed reduction of about 4 mph on trucks at Station 2. Likewise, trucks had a 2.57 mph net speed
reduction at Station 3. This reduction is statistically significant and indicates that placing of the second CMS reduced the average speed of trucks by about 3 mph at Station 3. Therefore, using two CMSs was effective in reducing the speed of trucks by an additional 3 mph.

Table 6.

Net Speed Reduction (mph) When Two CMSs Were Inside of Work Zone

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Between Stations 1 and 2</th>
<th>Between Stations 1 and 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Net Speed Reduction</td>
<td>T-test Inference</td>
</tr>
<tr>
<td>Cars</td>
<td>4.61</td>
<td>significant</td>
</tr>
<tr>
<td>Trucks</td>
<td>3.68</td>
<td>significant</td>
</tr>
</tbody>
</table>

Conclusions For Experiment 3

The results of Experiment 3 indicated that using two CMSs to display the speed limit and information messages in the work zone was effective in reducing the average speed of cars as well as trucks. The net reductions near the first CMS (at Station 2) were 4.6 mph for cars and 3.7 mph for trucks. The net reductions near the second CMS (at Station 3) were 4.7 mph on cars and 2.6 mph on trucks.

Displaying the messages on a CMS reduced the percentages of vehicles with excessive speeds, particularly the trucks at Station 2. The percentage of speeding trucks dropped from 92% to 74% at Station 2. It should be noted that the study did not measure the speed changes between Stations 2 and 3, thus it is not known whether the vehicles increased their speeds between Stations 2 and 3 or maintained the low speeds they had reached at Station 2.

The results for Experiment 3 indicate that cars and trucks reacted to the messages on the CMSs and reduced their speeds. The net speed reduction depended, particularly for cars, on the travel speed of the vehicles. Cars had larger speed reductions in Experiment 3 compared to Experiment 2. This reduction could partially be due to the higher speeds cars had at Station 1 in Experiment 3. Further studies are needed to support this finding and to establish the relationship between speed reduction and
velocity of vehicles.

Comparing the results from Experiments 2 and 3 indicates that
the net speed reductions for trucks near the first CMS were not
consistent, but at a location far from it the reductions were
consistent. On the other hand, the net speed reductions for cars
were consistently significant. Displaying the CMS messages reduced
the speed of cars immediately after passing the CMS, but not at a
point far from the CMS. The effects of the CMS messages on trucks,
however, showed an opposite trend. Although trucks did not
consistently reduce their speeds near the first CMS, trucks
traveled at reduced speeds after passing the CMS.
CONCLUSIONS

Displaying speed limit and information messages on a CMS placed in advance of a work zone (Experiment 1) reduced the average speed of cars and trucks by 2.8 mph and 1.4 mph, respectively, at a point near the beginning of the traffic control zone.

Displaying speed limit and information messages on a CMS placed in the work activity area (Experiment 2) was effective in reducing the average speed of cars by 1.7 mph at a point near the CMS (about 1000 ft. from it), but was no longer effective at a point far from the CMS (about 2 miles, but still inside the work activity area). On the other hand, the messages were not effective in reducing the average speed of trucks near the CMS, but reduced the speed by 3.7 mph far from the CMS. The data indicated that cars reacted by slowing down near the CMS, but the effect was not sustained at a point far from the CMS. However, trucks did not reduce their speeds immediately near the CMS, but traveled at a reduced speed far from the CMS.

Displaying speed limit and information messages on two CMS devices placed in the work zone activity area (Experiment 3) was effective in reducing the average speed of cars as well as trucks. The net reductions near the first CMS (at Station 2) were 4.6 mph for cars and 3.7 mph for trucks. The net reductions near the second CMS (at Station 3) were 4.7 mph on cars and 2.6 mph on trucks. When cars are traveling close to the speed limit, a smaller speed reduction was achieved than when they were traveling very fast. Displaying the messages on the CMS reduced the percentage of vehicles with excessive speeds, particularly the trucks at Station 2. The percentage of speeding trucks dropped from 92% to 74% at Station 2.

Comparing the results from Experiments 2 and 3 indicated that displaying the CMS messages reduced the speed of cars immediately after passing the CMS, but not at a point far from the CMS. The effects of the CMS messages on trucks, however, showed an opposite trend. Although trucks did not consistently reduce their speeds near the first CMS, trucks traveled at reduced speeds after passing the CMS. In general, displaying the messages not only reduced the average speeds, but also reduced the percentages of vehicles with excessive speeds.

RECOMMENDATIONS

The results from this study indicated that the messages on the CMS affected the speed of cars at a location close to the device; however, the impact on the trucks took place further from the CMS. Further studies are needed to determine the optimal distance from the CMS to the work space that would be most effective in reducing the speed of cars and trucks. Speed profiles of cars and trucks
should be used to determine the optimal location of the CMS inside the work activity area.

The net speed reduction seemed to be depended, particularly for cars, on the travel speed of the vehicles. Cars had larger speed reductions in Experiment 3 compared to Experiment 2. This reduction could partially be due to the higher speeds cars had at Station 1 in Experiment 3. Further studies are needed to support this finding and to establish the relationship between speed reduction and velocity of vehicles.

REFERENCES


APPENDIX A - DATA REDUCTION

A.1. Procedure

The vehicle speeds at each station were collected with mechanical traffic counters. The traffic counters were IRD Traffic Counter and Classifiers (TCC). These TCC had a capacity for the attachment of a maximum of four loops and four pneumatic road tubes. The counters were programmed to keep a record of individual vehicles. This was ascertained to be more accurate than having the traffic counter sort the data itself and store it in bins. More information about individual vehicles was available by not grouping them (putting them in bins). The accuracy of measurements was 1 mph for speed, 0.1 ft. for axle spacing, and 1 second for time headway. Each TCC has 64 K of memory, which can store up to 8,000 individually time-stamped vehicles. The memory of the counter was sufficient for one day of data collection. At the end of each day of data collection, the data was downloaded to an IBM PC using a program called TELECOMP V. The data was stored as an ASCII file on the PC.

A.2. Computer Program

In order to reduce the traffic data to meaningful results, a Fortran program was written to perform sorting and checking tasks on the raw data. The Fortran program, called TRAFFIC, deletes any duplicated entries from the file, separates the data according to lane traveled, computes the headway for successive vehicles in each lane, filters out erroneous data, and separates free flow traffic data from that of platooning vehicles. The following paragraphs briefly describe each of the tasks performed by the TRAFFIC program.

A.2.2. Headways

The time headway between successive vehicles was computed. The time at which each data record was read was converted to seconds, and the difference in time between successive vehicles gave the headway. If the headway was greater than 5 seconds, it was assumed that the vehicle was far enough from the preceding vehicle that it was considered to be traveling in free flow. When the headway was less than or equal to 5 seconds, it was assumed that the vehicle was traveling in a platoon, and therefore was influenced by the leading vehicle. Only free flow vehicles were considered in this study.
A.2.3. Erroneous Data

A careful review of the raw data indicated that there were occasional erroneous entries. The erroneous data may have occurred when the vehicles were following each other very closely. Erroneous data was also observed at Station 1 when two vehicles in two different lanes went over the tubes at the same time. The erroneous data was considered to be that which met any of the following conditions: very high or very low speeds (less than 30 mph or greater than 100 mph), number of axles greater than 5, very long or very short axle spacings (first axle spacing greater than 40 feet or less than 6.1 feet), and unreasonable axle spacings for a 3, 4 or 5-axle vehicle.

These decisions were made based upon review of raw data, truck and car dimensions, axle spacings, axle combinations for trucks, and axle combinations for cars pulling a trailer. The emphasis was to collect data from those vehicles typically traveling on the highway. For instance, vehicles with more than 5 axles were deleted because they were rare occurrences. Deleting the erroneous data increased the accuracy of the data used for analysis.

A.2.4. Free-Flow Traffic Data

The data of interest in this study is the free flow traffic data. Consequently, the free flow traffic data was separated based on the time headway as described above.
APPENDIX B - ONE CMS IN ADVANCE OF WORK ZONE (EXPERIMENT 1)

B.1. Description of Experiment 1

In Experiment 1, one CMS was placed in advance of the construction zone about 650 ft. before the "Road Construction 1 Mile" sign. The CMS was placed on the shoulder (half on the paved shoulder and the other half on the grass) approximately 6100 ft. before the lane closure taper. The locations of the CMS and the data collection stations are shown in Figure B.1. Two alternating messages were shown on the CMS. The messages were: "WORKERS AHEAD" and "SPEED LIMIT 45 MPH." Each message was displayed for three seconds.

B.2. Data Collection for Experiment 1

There were two data collection stations as shown in Figure B.1. At Station 1A, the drivers could not see the CMS because the trees inside a very flat horizontal curve (radius of about 4000 ft.) blocked the line of sight. Immediately after passing Station 1A, the drivers could see the CMS. The field data for Experiment 1 were collected on Monday, July 9, 1990, from 1:00 pm to 4:00 pm on the southbound lane of Interstate 57 near Mattoon, Illinois. Control data was collected on Tuesday, July 10, 1990, from 9 am to 12 noon. It was a typical hot and sunny summer day.

The data were collected on the outside lane using mechanical traffic counters with road tubes. It was found that the outside lane had speeds that were generally slower than the inside lane. Only free flow vehicles were used for data analysis, which eliminated the effects of platooning. A vehicle was considered free flow if its time headway was greater than 5 seconds.

B.3. Speed Characteristics for Experiment 1

In this section the speed characteristics for cars and trucks for Experiment 1 and its control data are discussed in detail. The speed limit was 65 mph for cars and 55 for trucks (trucks over 4 tons) outside the work zone. Station 1A was outside of the traffic control zone, but Station 2A was about 500 ft. past the first construction zone sign. A summary of speed statistics is given in Table B.1, and speed frequency distributions are shown in Figures B.2 through B.5.

B.3.1. Speed Characteristics in Control Data

Speed frequency distributions at Stations 1A and 2A are shown in Figures B.2 and B.4. The mean speeds for cars were about as
Figure B.1. Locations of Speed Stations and Changeable Message Sign (CMS) when placed in Advance of Work Zone on I-57 (Experiment 1)
Table B.1. Speed Statistics for Experiment 1  
(1 CMS in Advance of Work Zone)

<table>
<thead>
<tr>
<th></th>
<th>Control Data</th>
<th>1 CMS in advance of WZ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Station 1A (cars)</td>
<td>Station 2A (cars)</td>
</tr>
<tr>
<td>No. of Veh.</td>
<td>419</td>
<td>396</td>
</tr>
<tr>
<td></td>
<td>153</td>
<td>120</td>
</tr>
<tr>
<td>Mean speed</td>
<td>61.87</td>
<td>65.83</td>
</tr>
<tr>
<td></td>
<td>57.6</td>
<td>61.4</td>
</tr>
<tr>
<td>Min speed</td>
<td>48</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>Max speed</td>
<td>78</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>75</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>4.1</td>
<td>5.19</td>
</tr>
<tr>
<td></td>
<td>4.01</td>
<td>4.52</td>
</tr>
<tr>
<td>Percent exceeding</td>
<td>14.3</td>
<td>51.8</td>
</tr>
<tr>
<td>Speed limit</td>
<td>72.5</td>
<td>89.2</td>
</tr>
</tbody>
</table>
Figure B.2 Speed Frequency at Station 1A
For Control Data (Exp.1)

Percentage of Observations

Figure B.3 Speed Frequency at Station 1A
For 1 CMS in Advance of WZ (Exp.1)

Percentage of Observations
Figure B.4 Speed Frequency at Station 2A
For Control Data (Exp. 1)

Percentage of Observations

Figure B.5 Speed Frequency at Station 2A
For 1 CMS in Advance of WZ (Exp. 1)

Percentage of Observations
much as 4 mph higher than that of the trucks at Stations 1A and 2A. The speed variances of cars and trucks were statistically equal at both stations. Table B.1. Summary of Speed Statistics The standard deviations of the truck speeds were 4.0 and 4.5 mph at Stations 1A and 2A, respectively. The comparisons of speeds of cars to trucks are shown in Table B.2.

Table B.2.
Comparison of Speeds of Cars and Trucks for Experiment 1
(One CMS at Beginning of the Work Zone)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Station</th>
<th>Variances of Speed</th>
<th>Mean Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Prob&gt;F'</td>
<td>Inference</td>
</tr>
<tr>
<td>Control</td>
<td>1A</td>
<td>0.7399</td>
<td>equal</td>
</tr>
<tr>
<td></td>
<td>2A</td>
<td>0.0725</td>
<td>equal</td>
</tr>
<tr>
<td>CMS ON</td>
<td>1A</td>
<td>0.0032</td>
<td>unequal</td>
</tr>
<tr>
<td></td>
<td>2A</td>
<td>0.0002</td>
<td>unequal</td>
</tr>
</tbody>
</table>

The percentages of cars exceeding the speed limit were about 14% and 52% at Stations 1A and 2A, respectively. However, there were about 73% and 89% speeding trucks at Stations 1A and 2A, respectively. At Station 2A, the mean speed of cars was only 1 mph higher than the speed limit; however, trucks had a mean speed 6 mph higher than the speed limit. The percentage of speeding trucks was as much as 58% more than that of speeding cars at Station 1A, and 37% more than that of speeding cars at Station 2A. The percentages of vehicles exceeding a given speed are shown in Figures B.6 and B.7.

B.3.2. Speed Characteristics with 1 CMS in Advance of Work Zone

The percentages of cars exceeding the speed limit were 14% and 32% at Stations 1A and 2A, respectively. The average speeds of cars were about 2 to 4 mph lower than the speed limit at Stations 1A and 2A. At Station 1A, the trucks had the smallest speed variance which indicated that the trucks traveled at a more uniform speed. The mean speed of trucks was 57 mph at Station 1A and increased to 59 mph at Station 2A. The percent of speeding trucks was 63 at Station 1A and 81 at Station 2A. About 12 to 38% of trucks traveled faster than 60 mph at Stations 1A and 2A. Percentages of vehicles exceeding a given speed level are shown in Figures B.8 and B.9. The average speeds for cars were as much as 4 mph higher than those of trucks at Stations 1A and 2A (see Figure B.10). The mean speeds for both cars and trucks increased at
Figure B.6. Cars Exceeding Given Speed For Control Data (Exp. 1)

Figure B.7. Trucks Exceeding Given Speed For Control Data (Exp. 1)
Figure B.8. Cars Exceeding Given Speed For 1 CMS in Advance of WZ (Exp. 1)

Figure B.9. Trucks Exceeding Given Speed for 1 CMS in Advance of WZ (Exp 1)
Station 2A. The percentages of speeding trucks were much higher than those of cars at both Stations 1A and 2A. Comparison of the mean speed of cars to trucks indicated that the trucks were traveling slower than cars, as was expected. However, the speed difference between cars and trucks was much less than the 10 mph speed limit difference.

The reason for the lower average speeds at Stations 1A and 2A is perhaps due to the rough surface which resulted from milling of the pavement. Based on the research team’s field observations of the site, it is very unlikely that the low mean speeds were due to the horizontal curve before the CMS. The horizontal curve was very flat and most drivers would not have even noticed that they were inside a curve.

### B.4. Net Speed Reduction

In order to find out whether there was an additional speed reduction due to putting a CMS in advance of the construction zone, the net speed reductions at Station 2A were computed. The resulting net speed reductions are shown in Table B.3. The net speed reduction of cars at Station 2A was 2.78 mph. The result of
Table B.3.

Net Speed Reduction (mph) for 1 CMS in Advance of the Work Zone

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Between Stations 1A and 2A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Net Speed Reduction</td>
</tr>
<tr>
<td>Cars</td>
<td>2.78</td>
</tr>
<tr>
<td>Trucks</td>
<td>1.39</td>
</tr>
</tbody>
</table>

The t-test indicated that the difference is statistically significant. It means that due to putting the CMS in advance of the construction zone, car drivers reduced their speeds by about 3 mph (net speed reduction).

The trucks had a net speed reduction of 1.39 mph at Station 2A. This reduction is statistically significant. It indicated that because of the CMS the mean speed of trucks was additionally reduced by about 1.4 mph. Therefore, there was an additional net speed reduction of 1.4 mph on trucks due to placing the CMS in advance of the work zone. Although this difference is statistically significant, it is not a considerable speed reduction for practical purpose. It should be noted that in this study we only used speed as the criteria for evaluation of the CMS. Putting CMSs in work zones may have other benefits, such as increasing alertness of drivers, calling their attention to the work zone, etc., that were not considered in this study.

B.5. Conclusions For Experiment 1

The results of data analysis for Experiment 1 indicate that putting a CMS in advance of the construction zone caused a net speed reduction of 2.8 mph on cars and 1.4 mph on trucks. Also, placing the CMS in advance of the work zone reduced the percent of cars exceeding the speed limit. The amount of speeding cars decreased by 20%.

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