EVALUATION OF A RADAR ACTIVATED HORN
SYSTEM FOR SPEED CONTROL IN HIGHWAY
MAINTENANCE OPERATIONS

By
Rahim F. Benekohal
Jeffrey S. Linkenheld

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

Project IHR-014
ILLINOIS COOPERATIVE HIGHWAY RESEARCH PROGRAM

Conducted by the
DEPARTMENT OF CIVIL ENGINEERING
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

For the
ILLINOIS DEPARTMENT OF TRANSPORTATION
In Cooperation with the
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

DECEMBER 1990
EVALUATION OF A RADAR ACTIVATED HORN SYSTEM FOR SPEED CONTROL IN HIGHWAY MAINTENANCE OPERATIONS

Author(s): R. F. Benekehal, J. S. Linkenheld

Department of Civil Engineering
University of Illinois at Urbana-Champaign
Urbana, IL 61801

Sponsoring Agency Name and Address:
Illinois Department of Transportation
Bureau of Materials & Physical Research
126 E. Ash St.
Springfield, IL 62704

Study was conducted in cooperation with U.S. Department of Transportation, Federal Highway Administration. Study title "Investigation of Speed Control in Work Zones"

Abstract:
This study evaluated the speed reduction effects of providing an audible message to the speeding motorists approaching a highway striping crew. The audible system consisted of a radar unit which activated a horn when approaching vehicles exceeded a speed threshold. Speed data for 118 vehicles were collected and a speed reduction profile for each vehicle was generated. The data was divided into horn activated, horn not activated, and control groups. When the horn was activated, the average, maximum, and minimum speed reductions were 9.71, 17, and 4 mph at a distance about 750 ft from the horn. When the horn was not activated the average, max and min reductions were 3.5, 5, and 3 mph, respectively. As the detection distance decreased, the effectiveness of the horn system decreased too. The exact amount of additional speed reductions due to horn blasts alone could not be determined because of a small control data. However, the range of the additional speed reduction due to the horn was estimated to be 0-6 mph at 750 ft from the horn, and 0-2 at 500 ft from the horn. At a distance 750 ft from the horn the speed reduction effect of the horn was the greatest. The horn should be activated when a speeding vehicle is at a distance not less than 750 ft from the horn to give the drivers enough time to slow down before passing the truck. The horn system seemed to have some speed reduction effects on the motorists. However, noise problems and the human factors considerations of this system needs to be studied. These concerns may limit application of this device to very special cases. Further studies on the effectiveness of the system are needed.

Keywords:
Speed Control, Work Zone, Radar Activated System, Audible Message in Work Zone, Speed Reduction in Work Zone
ACKNOWLEDGMENT AND DISCLAIMER

The authors would like to thank the Illinois Department of Transportation for supporting this study, particularly Ken Wood of the Bureau of Traffic for the excellent cooperation and for providing the horn system, and IDOT District 5 for their help in collecting the data. The authors also wish to thank the Project Advisory Committee members for their comments and suggestions during this study.

This report was prepared in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

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.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>HORN SYSTEM DESCRIPTION</td>
<td>1</td>
</tr>
<tr>
<td>STUDY APPROACH</td>
<td>2</td>
</tr>
<tr>
<td>Data Collection</td>
<td>4</td>
</tr>
<tr>
<td>Data Reduction</td>
<td>7</td>
</tr>
<tr>
<td>STUDY FINDINGS</td>
<td>11</td>
</tr>
<tr>
<td>Speed Profile When the Horn Was Activated</td>
<td>11</td>
</tr>
<tr>
<td>Speed Profile For Control Group</td>
<td>18</td>
</tr>
<tr>
<td>Speed Profile When Horn Was Not Activated</td>
<td>20</td>
</tr>
<tr>
<td>Comparison of Speed Reductions</td>
<td>22</td>
</tr>
<tr>
<td>Comparison of Horn Activated and Horn Not Activated Data</td>
<td>22</td>
</tr>
<tr>
<td>Comparison of Horn Activated and Control Data</td>
<td>24</td>
</tr>
<tr>
<td>Comments from the Field Crew</td>
<td>26</td>
</tr>
<tr>
<td>Suggested Modifications</td>
<td>28</td>
</tr>
<tr>
<td>CONCLUSIONS AND RECOMMENDATIONS</td>
<td>29</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>30</td>
</tr>
<tr>
<td>Table</td>
<td>Page</td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>DETECTION DISTANCES, INITIAL SPEEDS, AND SPEED REDUCTIONS FOR HORN ACTIVATED CASE, CONTROL DATA, AND HORN NOT ACTIVATED CASE</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SCHEMATIC CONFIGURATION OF A RADAR ACTIVATED HORN SYSTEM ON A STRIPING OPERATION ON I-57</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>SPEED REDUCTION VS INITIAL SPEED FOR VEHICLES ACTIVATING THE HORN</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>REGRESSION OF SPEED REDUCTION VS INITIAL SPEED FOR VEHICLES ACTIVATING THE HORN</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>AVERAGE AND INDIVIDUAL SPEED REDUCTIONS FOR THE VEHICLES ACTIVATING THE HORN</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>AVERAGE AND INDIVIDUAL SPEED REDUCTIONS FOR THE VEHICLES IN THE CONTROL DATA</td>
<td>19</td>
</tr>
<tr>
<td>6</td>
<td>AVERAGE AND INDIVIDUAL SPEED REDUCTIONS FOR THE VEHICLES NOT ACTIVATING THE HORN</td>
<td>21</td>
</tr>
<tr>
<td>7</td>
<td>AVERAGE SPEED REDUCTIONS AT DIFFERENT POINTS FOR HORN ACTIVATED, CONTROL, AND HORN NOT ACTIVATED CASES</td>
<td>23</td>
</tr>
<tr>
<td>8</td>
<td>REGRESSION LINES FOR AVERAGE SPEED REDUCTIONS FOR HORN ACTIVATED, CONTROL, AND HORN NOT ACTIVATED CASES</td>
<td>29</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

This study was a part of "speed control methods in work zones" sponsored by the Illinois Department of Transportation (IDOT), in cooperation with the Federal Highway Administration. The Project Advisory Committee for the study identified several promising speed control techniques and recommended them for field evaluation. A radar activated audible message system was one of the techniques used. This study evaluated the speed reduction effects of providing an audible message to the speeding motorists approaching a highway striping crew on I-57, between Arcola and Effingham.

The horn system was set-up so that an oncoming vehicle with an approaching speed of 60 mph or greater would trigger the horn. Speed data for 118 vehicles were collected and a speed reduction profile for each vehicle was generated. The data was grouped into the following three conditions based on the initial approaching speed of the vehicles and horn status: (1) the horn was activated by vehicles traveling faster than 60 mph, (2) the horn was not activated because the vehicles were traveling slower than 60 mph, and (3) the horn was off and could not be activated by fast moving vehicles (control data). The initial approaching speed was the speed of a vehicle the first time appearing on the radar screen.

There were 76 vehicles in the first group, 29 vehicles in the second group, and the remaining 13 in the third group. The data for each group were further divided into subgroups representing the detection distances from the horn. The detection distances were: 1000, 750, 500, 400, 300, 200, 100 ft from the horn. The speed reductions, if any, for the 29 slower moving vehicles may not be due to the audible message because they did not activate the horn. The control data was limited in size. The study was a pilot study and the first attempt for field
evaluation of the system.

The data for all three groups indicated similar decreasing relationships between the detection distance from the horn and the average speed reduction. The average speed reductions at 1000 ft from the horn were less than the reductions at 750 ft or at 500 ft. The maximum average reductions for the horn activated, and the horn not activated cases, were at 750 ft, whereas for the control group it was at the detection distance approximately 500 ft from the horn. For all three cases, the average speed reduction decreased, if the vehicles were detected closer to the horn.

For the horn activated case the average speed reduction was 9.71 mph and the range was 4-17 mph at a distance approximately 750 ft from the horn. However, for the same group the average reduction was 0.9 mph and the range was 0-2 at a distance approximately 200 ft from the horn. The maximum reduction of 17 mph was observed when the approaching vehicles activated the horn around 750 ft from the truck, while the minimum speed reduction was observed when the approaching vehicles triggered the horn for the first time at a point about 200 ft from the truck.

For the control group the relationship between the average speed reduction and detection distance showed a similar decreasing pattern, as seen in the horn activated data. The maximum average speed reduction was 4.2 mph when the vehicles were detected about 500 ft from the truck. The amount of reduction decreased steadily as the detection distance was decreased from 500 ft to 200 ft. It should be noted that the number of observations was too small to generalize the findings from this control group. Plus, there were not any data points at 750 ft from the horn. Although the control data was limited, it showed a similar trend to the one observed for the horn activated case.
For the horn not activated case, the maximum average speed reduction was 3.50 mph at a distance 750 ft from the horn, but it was only 1.80 ft at a distance 200 ft from the horn. The amount of reduction remained almost constant for the distance from 750 to 300 ft; the vehicles reduced their speeds between 2 to 4 miles depending on the initial detection distance.

The speed reduction due to the audible message system may be due to the combined effect of the horn and the radar. A part of the speed reduction achieved when the horn was activated may have been due to seeing the striping vehicles or warning from radar detectors. To isolate the effect of the horn itself from the other factor, the control data should be compared with the data when the horn was activated. The speed reduction due to activating the horn alone would be the difference between the control data and the horn activated data. Because of a small sample size for the control group, this study was unable to determine the exact amount of additional speed reductions due to the horn blast. However, it was able to estimate the range of additional speed reductions the audible system had.

The estimated range of additional speed reductions due to the horn was obtained by finding the difference between the lines representing horn activated and horn not activated cases. Maximum additional speed reduction between horn activated and horn not activated group was about 6 mph at the detection distance of 750 ft. At 400 ft the additional speed reduction due to the horn was only about 1 mph. At the detection distance of 300 ft the horn did not show any additional effect, and closer to the horn the reduction was even lower than the horn not activated case.

The ranges for additional speed reductions between horn activated and control cases are estimated to be 0.6 mph at 750 ft, and 0.2 at 500 ft. The
range of the additional reduction became narrower as the detection distance decreased. Using the range one may estimate the additional speed reduction due to the horn to be as high as 6 mph and as low as 0 mph. Since the control group showed a higher speed reduction than the horn not activated case, it is reasonable to conclude that the horn would have an additional speed reduction effect greater than zero. The control data for this study was small. Further studies of effectiveness of this device are needed.

The horn should be activated when a speeding vehicle is at a distance not less than 750 ft from the horn to give the drivers enough time to slow down before passing the truck. When the horn was activated by a vehicle about 750 ft away from the truck, the approaching vehicle had 6.9-8.5 seconds to react before passing the truck. It is important to provide enough time for the vehicles to slow down after hearing the horn and before passing the crew. The horn was less effective for warning the vehicles closer to the truck and more effective for warning vehicles farther away from the truck.

The horn system seems to have some speed reduction effect on the motorists. However, noise problem and the human factors considerations of this system needs to be addressed. These concerns may limit application of this device to very special cases. Further studies on the effectiveness of the system are recommended. Some improvements on this system and the data collection procedures are suggested.
INTRODUCTION

Excessive speed of traffic in highway construction and maintenance zones, and finding means of reducing it to an acceptable level, has been a concern to many public and private agencies. The Illinois Department of Transportation (IDOT) in cooperation with the Federal Highway Administration sponsored a study on "speed control methods in work zones". The Project Advisory Committee for the study identified several promising speed control techniques and recommended them for field evaluation. A radar activated audible message system was one of the techniques identified for evaluation. This study evaluated the speed reduction effects of providing an audible message to the speeding motorists approaching a highway striping crew on I-57. It should be noted that there is no specification for the audible message system in the Manual on Uniform Traffic Control Devices (MUTCD) (1), because it is an experimental device.

The audible message was intended to warn the speeding motorists approaching the striping vehicles and to get them to slow down by presenting a new stimulus in the form of horn blasts. The study was conducted when the striping crew was painting edge and lane lines on Interstate 57, between Arcola and Effingham, on Monday, September 18, 1989. This study was a pilot program and a first attempt at collecting meaningful data in the field. This study was performed in cooperation with the paint striping crew from IDOT District 5, Paris, Illinois.

HORN SYSTEM DESCRIPTION

The audible message system consisted of a directional radar unit and a radar activated horn. The horn was activated by the radar when a threshold speed level was exceeded. The radar unit was a two piece (antenna and system unit)
modified Decatur Hunter model speed detection radar. The system unit of the radar had two windows to show speeds. On one screen, the radar showed closing speeds of the approaching vehicles, and on the other window it showed an adjustable trigger speed. The closing speed was the speed difference between the approaching vehicle and the vehicle carrying the radar unit. The trigger speed was set by the user to a value between 25 to 60 mph. The radar activated the horn when the closing speeds were greater than the trigger speed.

The horn itself is a Model WH30167-2 K13 air chime manufactured by the Nathan Manufacturing Division of Wagner Machinery. It carries a maximum audible range of three miles and a minimum audibility of one mile. The horn was carried in one of the striping trucks. The truck is able to generate 120 pounds of air pressure, which enables the horn to approach the maximum range. There are two pitches for the horn. The first is a c-sharp, operating at 277 cycles per second (cps), and the second is a pitch of g-natural, operating at 392 cps.

**STUDY APPROACH**

It was planned to collect speed and speed reduction profiles for vehicles exceeding a speed threshold when the horn was on and when it was off. Data was also collected for vehicles going below the speed threshold. Initial speed ($S$) of each vehicle was recorded when it was seen on the radar screen for the first time. For every vehicle, the amount of speed reduction (SR) at various detection distances from the horn (DDFH) was determined. The horn status (HS), whether it was on or off, at the time a vehicle passed a detection point was recorded. The radar status (RS), whether the radar transmitter was on or off, was also recorded.
This information was used to explore the relationship between the speed reduction and the other above mentioned parameters. The relationship may be expressed in the following form:

\[ SR = f (RS, HS, S, DDFH) \]

In this relationship the SR not only depends on an individual variable, but it may also depend to some combination of them. The following four combinations were used to classify a vehicle in the data reduction step:

A) RS=on, HS=on, S >= 60 mph,
B) RS=on, HS=on, S < 60 mph,
C) RS=on, HS=off, S >= 60 mph, and
D) RS=on, HS=off, S < 60 mph.

The reason for using "on" status for the horn is because the crew informed us that they use a radar signal transmitter during striping. For all four groups the DDFH was recorded for each vehicle. For data analysis purpose, the combinations B and D were grouped into one category because in both cases the vehicles were traveling below 60 mph and could not activate the horn. The details on the three groups are explained in the data reduction section.

To evaluate speed reduction effects of the horn system, data was collected when IDOT maintenance crew used this device, on an experimental basis, on a striping job on an interstate highway. The effectiveness of this device was measured in terms of the additional speed reduction the horn blasts may have caused. Other effects the horn system may have on motorists, or the community, either positive or negative, was not measured in this pilot study, but needs to be evaluated.
Data Collection

A schematic configuration of the radar activated horn system and the striping crew during data collection period is shown in Figure 1. The striping crew consisted of five vehicles. The first vehicle striped the lane line and the second truck striped the outside shoulder line. The third truck carried paint supplies. The fourth truck was also a supply truck which carried the horn system. The fifth vehicle was a pick-up truck which carried a variable message board to inform approaching motorists to move to the passing lane. The message said "WET PAINT, NEXT 3 MILES, STAY IN LEFT LANE." on three screens.

The radar unit was kept inside the fourth truck. The radar’s antenna was attached to the rear of the fourth truck facing the approaching traffic at a height of approximately six feet. The horn was attached to the rear of the same truck and was run off of the truck’s air brake system. The radar and horn were interconnected so that the horn was automatically activated when the trigger speeds were exceeded by the vehicle closing speeds. The trigger speed may be set by the user to a number from 25 to 60 mph in increments of five miles per hour (e.g. 25, 30, 35, etc). A threshold speed of 60 mph was used in this study because the speed limit was 65 for cars and 55 mph for trucks on the highway. This study did not evaluate the effects of using different speed threshold.

Data collection was performed by having a research assistant ride along in the truck containing the horn system to videotape the radar screens. The camcorder was equipped with a character generator that could produce a stopwatch on the tape. For an approaching vehicle, the time of first detection, speed, and duration of time the vehicle traveled at that speed were recorded on the tape. The time a vehicle passed the truck carrying the radar unit was also recorded. In order to know when the vehicle passed the truck, the research assistant was
FIGURE 1
SCHEMATIC CONFIGURATION OF A RADAR ACTIVATED HORN SYSTEM ON A STRIPING OPERATION ON I-57

TRUCK PAINTING LANE LINE

TRUCK PAINTING EDGE LINE

SUPPLY TRUCKS

SUPPLY TRUCK CARRYING THE SYSTEM

PICK-UP TRUCK

TRAVELED LANE

SHOULDER

RADAR UNIT

ANTENNA

HORN
required to waive his hand in front of the camera lens to establish a time mark.

The data was recorded for vehicles traveling alone or those in front of a platoon of vehicles. The speeds of these vehicles were unrestricted by vehicles in front of them. Vehicles traveling in packs (platoons) were not recorded, except for the lead vehicle in the platoon. Data was collected for approximately two hours when the horn was on and could be activated by a vehicle traveling at 60 mph or higher. The traveling speed of the truck was monitored at various points on the trip. The speed of the truck seemed to vary between 10 and 15 miles per hour (mph), and was confirmed by occasional checks of the speedometer. Although the speedometer reading was adequate in this study, it is recommended that in future studies the truck speed be monitored by a more precise method than the using the odometer.

Data was collected on travel speed of the striping crew, closing speed of vehicles, and duration of time an approaching vehicle traveled at a given speed. As the radar sensed a vehicle approaching, the closing speed of the vehicle was displayed on one window, along with the trigger speed on the other window. It should be noted that the speed shown on the radar’s screen represented the closing speed of the oncoming vehicles and not the actual speed. The actual approach speed of a vehicle would be the sum of the closing speed and the travel speed of the striping truck.

The horn was activated when a closing speed was greater than the trigger speed. The trigger speed was set so that an oncoming vehicle with an approach speed of 60 mph or greater would trigger the horn. This means the trigger speed of the radar was changed depending on the traveling speed of the truck. When the truck was traveling at a speed of 10 mph, the trigger speed was set to 50. Likewise, when the truck was traveling 15 mph the trigger speed was set to 45.
When the horn was on (fast moving vehicles could activate the horn), the speed profiles for 98 vehicles were obtained from the video tapes. Based on the initial approach speed of these vehicles, they were grouped into over 60 mph and under 60 mph. The initial approach speed is the approach speed of a vehicle the first time seen on the radar screen. The initial approach speed of 76 of them was 60 mph or greater, and the remaining 22 vehicles had an initial approach speed of less than 60 mph.

Data was also collected when the horn system was off (the horn could not be activated by the vehicles). It should be noted that the radar transmitter was on when the horn was on and off. The radar transmitter was kept on all the time because the striping crew used a radar transmitter in addition to the one used by the research team. This part of data was collected near the end of the day for a period of about half an hour (at that time the crew ended striping and the research team was unable to collect further data). This portion of the data was collected when the radar was on and the horn was off (the horn could not be activated even by the fast moving vehicles). From the video tapes taken during this time period, speed profiles for 21 vehicles were determined. The initial approach speeds of 13 vehicles were 60 or higher, one vehicle showed speed increase which was not used, and the remaining seven vehicles had initial approach speeds of less than 60 mph. Later seven vehicles were added to the other 22 slow moving vehicles.

Data Reduction

The data reduction involved viewing the video tapes on a VCR with forward and backward frame-by-frame advancing feature. Such capability allowed us to find precisely the time a vehicle passed a point on the road. For a given
vehicle, the first time the speed appeared on the screen marked the beginning of speed profile. The end of the speed profile was when the vehicle passed the truck. Because of the frame by frame advancing capability of the VCR used, the times could be recorded to within 1/30 of a second accuracy. Tenths of seconds were deemed accurate enough and were used for this study. The time that the vehicle passed the truck carrying the horn was recorded by the hand mark from the research assistant.

Since the two end point speeds (speed of the vehicle displayed on the window for the first time and speed when the vehicle passed the truck) were established, and the intermediate speeds were preserved on the tape, a speed reduction profile could be generated for every isolated vehicle passing the truck. These speed reduction profiles were generated using information about the first time a vehicle was detected, speed of the vehicle, duration of the time a vehicle traveled at a given speed, and time the vehicle passed the truck. The information was extracted from the video tape and was entered into a FORTRAN program that back-calculated the distance between a vehicle and the horn and the vehicle speeds at different detection distances from the truck carrying the horn.

From the video tape the time, speed, and duration of a speed level is recorded. From the information the location of a vehicle is back-calculated for each time period. An example of how the calculations are carried out is given below.
<table>
<thead>
<tr>
<th>Time shown on Video Tape</th>
<th>Speed</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Hours) (Minutes) (Seconds)</td>
<td>(MPH)</td>
<td>(Feet)</td>
</tr>
<tr>
<td>0 8 51.8</td>
<td>47</td>
<td>387.1</td>
</tr>
<tr>
<td>0 8 54.9</td>
<td>46</td>
<td>173.4</td>
</tr>
<tr>
<td>0 8 56.6</td>
<td>45</td>
<td>58.7</td>
</tr>
<tr>
<td>0 8 57.0</td>
<td>44</td>
<td>32.3</td>
</tr>
<tr>
<td>0 8 57.5</td>
<td>44</td>
<td>(passed truck)</td>
</tr>
</tbody>
</table>

The distance of a vehicle from the truck carrying the horn is computed as:

\[ D_{t-dt} = V_{t-dt} \cdot (dt) + D_t \]

Where:

- \( D_{t-dt} \) is the distance between the approaching vehicle and the truck carrying the horn system at time \( t-dt \)
- \( V_{t-dt} \) is the approaching speed of the vehicle in time interval \( t \) and \( t-dt \)
- \( D_t \) is the distance between the approaching vehicle and the truck carrying the horn system at time \( t \)
- \( dt \) is the time interval between \( t \) and \( t-dt \)

For instance, the distance the vehicle traveled while approaching the truck is 
\((00:08:57.5 - 00:08:57.0)(44)(88/60) = 32.3 \text{ feet}, \text{ at 44 mph. This distance is added to the next calculation of (00:08:57.0 - 00:08:56.6)(45)(88/60) = 26.4 feet. This process was repeated until the initial detection time and speed of the vehicle in question was reached. For instance, we know that when the vehicle closing speed changed from 46 to 45 mph, it was 173.4 feet from the truck.} \]
The actual speed of the approaching vehicle would be the closing speed plus speed of the truck. For this example, if the truck speed was 15 mph, the approaching speed of the vehicle was between 62 and 59 mph. Speed profile for each vehicle was tabulated in this manner. From the profiles one can determine the speed of a vehicle at a distance from the horn.

The data was grouped into the following three conditions based on the initial approaching speed of the vehicles and horn status: (1) the horn was activated by vehicles traveling faster than 60 mph (combination A), (2) the horn was not activated because the vehicles were traveling below 60 mph (combination B plus D), and (3) the horn was off and could not be activated by fast moving vehicles (combination C). The third group is the control data for this study. There were 76 vehicles in the first group (horn activated), 29 in the second group (horn not activated), and the remaining 13 in the third group (control data). Speed and speed reduction profile for each of the 118 vehicles was generated.

It should be noted that the control data is limited in size. The research team has not been able to collect data using this device in a similar application in real world traffic conditions. This is mainly due to unwillingness of the crew to listen to a high level of noise over an extended period of time. Thus, the results reported here are based on the only available data that has a limited control group. The speed reductions for the 29 slower moving vehicles, if any, are not due to the audible message because they did not activate the horn.
STUDY FINDINGS

The study findings are reported in four parts. The first part examines the effect of activating the horn (horn activated) on speed of the vehicles traveled faster than the threshold. The second part reports on the effect of using the radar, but not the horn on speed of fast moving vehicles in the control group (control data). The third part looks at the speed of the vehicles traveled slower than the threshold and did not activate the horn (horn not activated). The fourth part discusses the speed reduction effect of the horn system.

Speed Profile When The Horn Was Activated

All of the vehicles in this category were traveling faster than the threshold of 60 mph. The total speed reduction for a vehicle in this group was determined as the difference in speed when the vehicle was first detected minus the speed when the vehicle passed the truck. The total speed reduction was plotted against the initial speed (speed of vehicle when it was detected by radar for the first time), as shown in Figure 2. Figure 2 indicated the amount of speed reduction did not depend on the initial speed of a vehicle, when the detection distance was not considered.

The data was further examined to see if considering the detection distance would improve the relationship between the detection distance and the amount of speed reduction. The data was divided into several groups, each representing a range of detection distance from the truck carrying the horn. The ranges were represented by the following detection distances: 1000 ft, 750 ft, 500 ft, 400 ft, 300 ft, 200 ft, 100 ft, and passing the truck. For example, 1000 ft from the truck represented any initial speed detection at a distance 875 ft or greater from the truck. Speed reductions for each vehicle were computed from the speed
FIGURE 2
SPEED REDUCTION VS INITIAL SPEED
FOR VEHICLES ACTIVATING THE HORN

Total Speed Reduction (mph)

Initial Speed (mph)

Detected first at

* 750 ft  
+ 500 ft  
* 400 ft  
* 300 ft  
× 200 ft  
○ 1000 ft
profile of that vehicle at the detection points. The number of observations in each group and the average speed for the group are given in Table 1. Some vehicles were detected far from the truck (over 1000 ft), but others were closer to the truck. The highest percentage of observations was about 300 feet from the truck.

Effect of the initial speed and the first detection distance on the total speed reduction was examined for the grouped data. To examine the effect of initial speed on speed reduction at a given detection distance, regression analyses of the total speed reduction versus initial detection speeds were carried out for the grouped data (grouped based on the first detection distance). One regression line was obtained for each detection distance, as shown in Figure 3. Because the data for a given detection distance was very scattered, the $R^2$ values for these lines were very low, indicating that the correlation between initial speed and total speed reduction was very weak. More data points may improve the correlation between the two variables.

The relationship shown in Figure 3, although coming from the limited data, seemed to indicate that the faster vehicles slowed down more than the slower vehicles, if the horn was activated about 750 ft from the truck. However, for the detection distances of 500 ft, or less, the slower vehicles reduced speed at least as much as the faster vehicles. The maximum $R^2$ was 0.17 for the vehicles first detected around 400 ft. The regression lines do not show a consistent trend. One should be very cautious in generalizing the trends shown by the regression lines because of low $R^2$ and a small sample size at a given distance.

Although the regression lines did not show a consistent trend, the plot of average speed reduction versus the detection distance clearly indicated a relationship between the two parameters. The average speed reduction decreased
<table>
<thead>
<tr>
<th>Detection Distance (ft)</th>
<th>No. Of Obs</th>
<th>Initial speed</th>
<th>Speed Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average Max</td>
<td>Min</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(mph) (mph)</td>
<td>(mph)</td>
</tr>
<tr>
<td>HORN ACTIVATED GROUP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>1</td>
<td>69.0 69</td>
<td>69</td>
</tr>
<tr>
<td>750</td>
<td>7</td>
<td>66.9 74</td>
<td>60</td>
</tr>
<tr>
<td>500</td>
<td>16</td>
<td>65.0 72</td>
<td>60</td>
</tr>
<tr>
<td>400</td>
<td>15</td>
<td>65.3 75</td>
<td>60</td>
</tr>
<tr>
<td>300</td>
<td>26</td>
<td>65.0 75</td>
<td>60</td>
</tr>
<tr>
<td>200</td>
<td>11</td>
<td>65.0 74</td>
<td>60</td>
</tr>
<tr>
<td>CONTROL GROUP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>2</td>
<td>63.00 65</td>
<td>61</td>
</tr>
<tr>
<td>500</td>
<td>6</td>
<td>64.50 67</td>
<td>61</td>
</tr>
<tr>
<td>400</td>
<td>2</td>
<td>69.00 71</td>
<td>67</td>
</tr>
<tr>
<td>300</td>
<td>3</td>
<td>63.00 65</td>
<td>62</td>
</tr>
<tr>
<td>HORN NOT ACTIVATED GROUP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>1</td>
<td>55.0 55</td>
<td>55</td>
</tr>
<tr>
<td>750</td>
<td>4</td>
<td>52.5 59</td>
<td>39</td>
</tr>
<tr>
<td>500</td>
<td>6</td>
<td>55.5 57</td>
<td>53</td>
</tr>
<tr>
<td>400</td>
<td>8</td>
<td>55.3 59</td>
<td>49</td>
</tr>
<tr>
<td>300</td>
<td>5</td>
<td>57.4 59</td>
<td>55</td>
</tr>
<tr>
<td>200</td>
<td>5</td>
<td>52.6 58</td>
<td>45</td>
</tr>
</tbody>
</table>

TOATL 118
FIGURE 3
REGRESSION OF SPEED REDUCTION VS INITIAL SPEED FOR VEHICLES ACTIVATING THE HORN

Total Speed Reduction (mph)

Initial Speed (mph)

detected first at

- 750 ft  - 500 ft  - 400 ft  - 300 ft  - 200 ft
when a vehicle was detected closer to the truck. For example, the average speed reduction about 750 ft from the truck was 9.71 mph, about 400 ft from the truck the reduction was 4.0 mph, and about 200 ft from the truck the reduction was only 0.9 mph. This trend is clearly shown in Figure 4. The trend indicated that a higher speed reduction was achieved when a vehicle was detected far from the truck. There was only 1 data point farther than 750 ft from the truck. The results indicate that to obtain a higher speed reduction the system should be aimed at the vehicles about 750 ft from the truck.

A maximum reduction of 17 mph and a minimum reduction 4 mph were observed when the approaching vehicles activated the horn around 750 ft from the truck. Minimum speed reduction was observed when the approaching vehicles triggered the horn for the first time at a point about 200 ft from the truck. About 200 ft from the truck the maximum and minimum speed reductions were 2 mph and 0 mph, respectively.

For the vehicles with a detection distance of 200 to 750, there is a noticeable decreasing relationship between the average speed reduction and the detection distance from the horn. The speed reduction is greatest when the vehicle is detected about 750 ft from the truck, but the amount of reduction decreases steadily as the detection distance is shortened from 750 ft to 200 ft. The relationship between speed reduction and detection distance is shown in Figure 8. The R² value for the regression line for horn activated condition was 0.47. Since speed reduction at 1000 ft from the truck was only for one data point it was not included in the regression analysis.
FIGURE 4. AVERAGE AND INDIVIDUAL SPEED REDUCTIONS FOR THE VEHICLES ACTIVATING THE HORN

- reduction for one vehicle  - average reduction

Note: Repeated observations are shown by one data point
Speed Profile For Control Group

For the control data, a motorist speed reduction, if any, could be due to visual observation of the striping trucks, or due to warning from his/her radar detector, or both. Since the striping crew normally uses a radar transmitter, the control data was collected when the radar was on and the horn was off. Thus, the approaching vehicles could not activate the horn (the horn was off in all cases). The control data consisted of much fewer observations (13 vehicles, for explanations see the data collection and data reduction sections) than the horn activated data. For the control data, the summary of the speeds and speed reductions at the detection points is given in Table 1.

For the control group the relationship between the average speed reduction and detection distance showed a similar decreasing pattern as seen in the horn activated data. A plot of the average speed reduction versus the detection distance from the horn is shown in Figure 5. The maximum average speed reduction was 4.2 mph when the vehicles were detected about 500 ft from the truck. The reduction at 750 ft from the horn is not known because the control group did not have any observations at this point. The speed reduction at 1000 ft is coming from two data points and tends to confirm a similar observation on the horn activated data that at this point the speed reduction is low.

The amount of reduction decreases steadily as the detection distance is shortened from 500 ft to 200 ft. The regression analysis of the total speed reduction versus initial detection speeds for detection distances of 500 ft or less was performed. The relationship is shown in Figure 8. The \( R^2 \) for the regression line for the control group was 0.47. It should be noted that the number of observations are too small to generalize the findings from this control group. Plus, there was not any data points at 750 ft from the horn. Although
FIGURE 5. AVERAGE AND INDIVIDUAL SPEED REDUCTIONS FOR THE VEHICLES IN THE CONTROL DATA

- ◇ reduction for one vehicle  ▲ average reduction

Note: Repeated observations are shown by one data point
Note: The data for control group was very small
the control data was limited, it showed a trend similar to the one observed for the horn activated case.

**Speed Profile When Horn Was Not Activated**

For the 29 motorists with initial speeds of less than 60 mph, the speed reduction may be due to visual observation of the striping trucks or due to warnings from their radar detectors, but not due to the horn blasts. These vehicles did not activate the horn because their speed was below the threshold. A summary of the speeds and speed reductions at different detection points is given in Table 1. The analysis performed for this group was similar to that for the control group.

The results of the total speed reduction versus the detection distance from the horn are shown in Figure 6. A similar decreasing trend was observed between the detection distance and the average speed reduction. The average speed reduction was 3.50 mph at a distance 750 ft from the horn, but it was only 1.80 ft at 200 ft from the horn. There was only one observation at 1000 ft which showed no speed reduction. The average speed reduction for the vehicles detected first at 400 ft from the truck was slightly higher than the reduction at 500 ft.

The amount of reduction remained almost constant for the distance of from 750 to 300 ft. The regression line for the average speed reduction versus initial detection distance, for the range of 300-750 ft, is shown in Figure 8. The $R^2$ value for this line was only 0.14. It can be seen that this line has a very flat slope compared to the line for horn activated case. The regression line for this data shows that the vehicles reduced their speeds from 2 to 4 miles depending on the initial detection speed.
FIGURE 6. AVERAGE AND INDIVIDUAL SPEED REDUCTIONS FOR THE VEHICLES NOT ACTIVATING THE HORN

- reduction for one vehicle
- average reduction

Note: Repeated observations are shown by one data point
Comparison of Speed Reductions

Similar trends were observed on the plots of speed reduction versus detection distance for the horn activated case, horn not activated case, and the control group (although control data had a limited number of observations). Figure 7 shows the average speed reductions for the three conditions at different detection distances. For all three cases the reductions at 1000 ft from the horn are less than the reductions at 750 ft or at 500 ft from the horn. The data showed that the vehicles detected far from the truck were not necessarily traveling at a faster speed than the vehicle detected closer to the horn. The data collected did not show the vehicle type. It is reasonable to assume that the vehicles detected at 1000 ft were mostly trucks or other larger vehicles, and those detected closer to the horn were mostly automobiles. It is suggested to record vehicle type in future data collection.

Comparison of Horn Activated and Horn Not Activated Data

For horn activated and horn not activated cases, the average speed reductions were maximum when approaching vehicles were detected about 750 ft away from the horn (Figure 7 and Table 1). When the horn was activated by a vehicle about 750 ft away from the truck, the approaching vehicle had 6.9-8.5 seconds to react before passing the truck. However, if the horn sounded when the vehicle was at 400 ft from the truck there was only 3.6-4.5 seconds to slow down before passing the truck. It is important to provide enough time for the vehicles to slow down after hearing the horn and before passing the crew. This time will depend on the speed of vehicle and its distance from the horn. The distance that provided the highest average speed reduction was about 750 ft from the truck, and the time before reaching the crew was around 8 seconds.
FIGURE 7. AVERAGE SPEED REDUCTIONS AT DIFFERENT POINTS FOR HORN ACTIVATED, CONTROL, AND HORN NOT ACTIVATED CASES

Note: The number of observations in the control data was very small
At the detection distance of 750 ft, the maximum additional speed reduction between horn activated and horn not activated group is about 6 mph (Figures 7 and 8). The speed reduction becomes less as the detection distance decreases. At 400 ft the additional speed reduction due to horn was only about 1 mph. At the detection distance of 300 ft the horn did not show additional effect, and closer to the horn the reduction was even lower than the horn not activated case.

Thus, the horn was less effective for warning the vehicles closer to the truck and more effective for warning the vehicles far from the truck. Based on the data from this pilot study, the horn should be activated when a speeding vehicle is at a distance not less than 750 ft from the horn. This would give the drivers enough time to slow down before passing the truck. The suggested distance is greater than the stopping sight distance of 550 to 725 ft recommended by AASHTO (2) for a vehicle traveling at 65 mph.

Comparison of Horn Activated and Control Data

The speed reduction due to the audible message system is due to the combined effect of the horn and the radar. A part of the speed reduction achieved when the horn was activated may have been due to some factors other than the horn blasts. Seeing the striping vehicles and the message on the pick-up truck may have caused some speed reduction. Also, the vehicles with radar detectors may have reduced their speeds due to the radar signals alone. To isolate the effect of the horn itself from the other factor, the control data should be compared with the data when the horn was activated.

The speed reduction gained by activating the horn only would be the difference between the control data and the horn activated data as shown in Figures 7 and 8. Because of a small sample size for the control group, this
FIGURE 8. REGRESSION LINES FOR AVERAGE SPEED REDUCTIONS FOR HORN ACTIVATED, CONTROL, AND HORN NOT ACTIVATED CASES

- x horn activated data  + control data  A horn not activated data

Note: The number of observations in the control data was very small
Note: For the regression lines data at 1000 ft were not used
study was unable to determine the exact amount of additional speed reductions due to the horn blast. However, it was able to estimate the range of additional speed reductions the audible system had. The estimated range of additional speed reductions due to the horn is obtained using Figures 7 and 8. The difference between the lines representing horn activated group and horn not activated cases is considered a reasonable range for the speed reduction effect of the horn.

Comparison of the speed reduction plots (Figures 7 and 8) for the three cases indicated that the control group had a speed reduction less than the horn activated case but, more than the horn not activated case. The ranges for additional speed reductions between horn activated and control cases are estimated to be 0-6 mph at 750 ft, and 0-2 at 500 ft. Thus, using this range one may estimate the additional speed reduction due to the horn to be as high as 6 mph and as low as 0 mph. However, data showed that the control group had a higher speed reduction than the horn not activated case. Therefore, it may be concluded the horn would have an additional speed reduction effect of greater than zero.

The vertical distances between the lines for horn activated and horn not activated cases in Figures 7 and 8 would estimate the range at other detection distances. The range of the additional reduction becomes narrower as the detection distance decreases. Figures 7 and 8 may be used for estimating the range of the additional speed reductions, however it is not advisable to read the reduction directly from these figures. Further field evaluations, if possible, are needed to determine the exact amount of additional speed reductions.

Comments from the Field Crew

The field crew and the research assistant made the following observations and comments about their perception of the general effectiveness of the horn
system: They observed that the horn was effective some of the time. In addition to the audible message, the radar signals activated the radar detectors used by the motorists and kept the truck drivers more alert when passing the construction area. The motorists thought the signal was police radar and started talking on the CB radio, keeping them awake and alert. However, the effect of the radar signal diminished when the motorists figured out that the signals were produced by the paint truck and not the state police.

The noise from the horn was annoying for the crew. Drivers of the truck carrying the horn and the driver of the pick-up truck complained about the amount of noise from the horn. They said that nobody would want to drive the horn truck because the noise to the driver is too much.

Hearing the horn blasts did not seem to cause a sudden speed reduction from the drivers. Reaction of drivers to the horn system, other than the speed reduction, was not studied in this project, but needs to be studied. Some drivers with very loud stereos may not hear the horn. In normal driving condition the horn could be heard clearly a few thousands feet before the truck.

The truck must follow the painting vehicles within a reasonable distance, or the effect of the speed reduction will be lost as cars pass the horn and accelerate to their former speeds.

The radar seemed to activate for only two or three blasts for many of the cars. The radar blasted at everybody once a fast moving vehicle activated it. The radar picked up the trucks much farther than cars. The radar antenna should be mounted on the driver's side and aimed at the proper angle in order to pick up the cars earlier. It seemed as though the cars would speed up again immediately after they passed the horn.
Suggested Modifications

With the current set-up the radar measures relative speed of the approaching and radar carrying vehicles. The actual speed of approaching vehicle is not directly measured, but computed from the truck speed and the closing speed of the approaching vehicle. Possible improvements to this set-up would be assigning another person to monitor the speed of the truck, or using another moving radar to monitor the truck speed.

The truck carrying the horn should be near the paint striping truck. In the field test, the truck was so far behind the paint crew (about 0.5 miles or more) that a fair percentage of the cars passed the horn and proceeded to accelerate as they cut across the fresh paint into the right hand lane. The driver of the truck thought the passenger cars were ignoring the message he was conveying. Indeed they were, but if the gap to the paint crew were shortened, the temptation would be eliminated.

A consistent driving plan should be observed by the striping crew. The message board truck was found to be in the outside driving lane some of the time. This would cause vehicles to slow down before they came under the influence of the horn truck. The last truck, displaying the message board, is required to drive on the shoulder in order to minimize the effect of disrupting the normal traffic flow.

Vehicle type should be recorded and information of presence of radar detector in the approaching vehicle should be gathered. This information can be collected easily when the system is used in a stationary mode. On a moving operation such as the striping crew it is difficult to determine every information needed. For instance, in this study the speed reduction effect of the horn blasts on car following the leader of a platoon of vehicles is not
known. This type of data could not be collected with the equipment used in this project.

There should be a sign (or signs) before the horn to warn the drivers about the horn blasts that may be heard. Another sign (or signs) asking drivers to take a specific action should be provided. The latter sign may ask them to slow down or use more caution in passing the crew. The horn blast by itself does not tell the drivers what to do and some drivers may not know that it is the message for speed reduction. Asking the drivers to take a specific action may increase the effectiveness of this device. Other human factors considerations of this device (e.g. sudden reaction to horn, noise effects on crew close to horn, effects on other drivers) need to be studied.

CONCLUSIONS AND RECOMMENDATIONS

The data seems to indicate that the audible message system caused some speed reduction on the fast moving vehicles. As the first detection distance decreased, the effectiveness of the horn system decreased too. There appears to be a distance not less than 750 ft where the speed reduction effects of the horn was the greatest. When the horn system was activated, the average speed reduction was 9.71 mph, the maximum reduction was 17 mph, and the minimum speed reduction was 4 mph at a point about 750 ft from the horn. These reductions may be due to the combined effect of horn, radar detector, and seeing the crew. The range of additional speed reductions due to the horn blasts only is estimated to be 0-6 mph at 750 ft, and 0-2 mph at 500 ft from the horn. This study found the speed reduction ranges for the horn system, but was unable to determine the exact amount of the reductions because only a small control sample could be collected.
This pilot study suggested some improvement on the use of this system and the data collection method that should be implemented in future studies. With the improved detection techniques and larger control data sets, further studies may lead to more conclusive evidence on effectiveness of the audible system. The system might be a viable alternative warning device under certain conditions. However, the noise problem may limit application of this device to very special cases. This horn system may also be used as device to warn the construction crew about very fast moving vehicles. Further studies on the effectiveness of the system in work zones and the human factors considerations are needed.

REFERENCES
