SPEED REDUCTION METHODS AND STUDIES IN WORK ZONES: A SUMMARY OF FINDINGS

By

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on
Investigation of speed control methods in work zones

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The objectives of this project were to determine the effectiveness of speed control methods and study traffic behavior in construction zones. This report provides a brief introduction and a summary of findings from the following reports which were prepared as part of this study:

5. Speed Reduction Effects of Changeable Message Signs in a Construction Zone.
8. Speed Reduction Profiles of Vehicles in a Highway Construction zone.

Data only for those vehicles in free flow traffic are used for speed reduction evaluation. A vehicle was considered to be in free flow traffic when its time headway was greater than 5 seconds.
ACKNOWLEDGMENT AND DISCLAIMER

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This report contains a summary of all published reports for the study. Individual reports were prepared with the assistance of many graduate students at the University of Illinois working with the author. The contributions of my co-authors: A. Hashmi, L. Kastel, J. Linkenheld, R. Orloski, P. Resende, J. Shu, I. Suhale, L. Wang and W. Zhao on individual reports are greatly appreciated. The author would also like to thank the Project Advisory Committee members for their comments and suggestions, and R. Pembroke and C. Wienrank for the review of the report.

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGMENT AND DISCLAIMER</td>
<td>iii</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2. EVALUATION AND SUMMARY OF STUDIES IN SPEED CONTROL METHODS IN WORK ZONES</td>
<td>4</td>
</tr>
<tr>
<td>3. EVALUATION OF A RADAR-ACTIVATED HORN SYSTEM FOR SPEED CONTROL IN HIGHWAY MAINTENANCE OPERATIONS</td>
<td>5</td>
</tr>
<tr>
<td>Introduction</td>
<td>5</td>
</tr>
<tr>
<td>Summary of Findings</td>
<td>5</td>
</tr>
<tr>
<td>Recommendations</td>
<td>7</td>
</tr>
<tr>
<td>4. SURVEY OF DRIVER’S OPINION ABOUT WORK ZONE TRAFFIC CONTROL ON A RURAL HIGHWAY</td>
<td>8</td>
</tr>
<tr>
<td>Introduction</td>
<td>8</td>
</tr>
<tr>
<td>Summary of Findings</td>
<td>8</td>
</tr>
<tr>
<td>Recommendations</td>
<td>10</td>
</tr>
<tr>
<td>5. SPEED REDUCTION EFFECTS OF DRONE RADAR IN RURAL INTERSTATE WORK ZONES</td>
<td>12</td>
</tr>
<tr>
<td>Introduction</td>
<td>12</td>
</tr>
<tr>
<td>Summary of Findings from 1 Radar Experiment at Site 1</td>
<td>13</td>
</tr>
<tr>
<td>Summary of Findings From 1 Radar Experiment at Site 2</td>
<td>14</td>
</tr>
<tr>
<td>Summary of Findings from 2 Radar Experiment at Site 2</td>
<td>14</td>
</tr>
<tr>
<td>Recommendations</td>
<td>15</td>
</tr>
<tr>
<td>6. SPEED REDUCTION EFFECTS OF CHANGEABLE MESSAGE SIGNS IN A CONSTRUCTION ZONE</td>
<td>16</td>
</tr>
<tr>
<td>Introduction</td>
<td>16</td>
</tr>
<tr>
<td>Experiment 1 – One CMS in Advance of Work Zone</td>
<td>16</td>
</tr>
<tr>
<td>Experiment 2 – One CMS Inside the Work Zone</td>
<td>17</td>
</tr>
<tr>
<td>Experiment 3 – Two CMSs Inside of the Work Zone</td>
<td>17</td>
</tr>
<tr>
<td>Conclusions</td>
<td>17</td>
</tr>
<tr>
<td>Recommendations</td>
<td>18</td>
</tr>
<tr>
<td>7. EFFECTS OF POLICE PRESENCE ON SPEED IN A HIGHWAY WORK ZONE: CIRCULATING MARKED POLICE CAR EXPERIMENT</td>
<td>20</td>
</tr>
<tr>
<td>Introduction</td>
<td>20</td>
</tr>
<tr>
<td>Conclusions</td>
<td>22</td>
</tr>
<tr>
<td>Recommendations</td>
<td>23</td>
</tr>
<tr>
<td>8. EVALUATION OF WORK ZONE SPEED LIMIT SIGNS WITH STROBE LIGHTS</td>
<td>24</td>
</tr>
<tr>
<td>Introduction</td>
<td>24</td>
</tr>
<tr>
<td>Conclusions for Data Set 1</td>
<td>24</td>
</tr>
<tr>
<td>Conclusions for Data Set 2</td>
<td>25</td>
</tr>
</tbody>
</table>

iv
Conclusions for Data Set 3 .......................... 25
Summary of Findings ............................... 25

9. SPEED REDUCTION PROFILES OF VEHICLES
   IN A HIGHWAY CONSTRUCTION ZONE ............ 26
Introduction ....................................... 26
Conclusions ........................................ 29
   Speed Characteristics .......................... 29
   Driver Categories ............................... 29
   Speed Reductions ................................ 30
   Speed Groups .................................... 30
Recommendations ................................. 33

10. REFERENCES ....................................... 34
1. INTRODUCTION

The objectives of this project were to determine the effectiveness of speed control methods and study traffic behavior in construction zones. Potential candidate speed reduction methods and traffic flow studies were identified, in collaboration with the Illinois Department of Transportation (IDOT). The candidates are:

A. Trained flagger vs contractor flagger.
B. Police presence in work zone.
C. Changeable message signs (CMS) treatment
D. Passive Radar (drone radar).
E. Radar-activated speed limit sign.
F. Radar-activated audible message.
G. Radar-activated flashing beacon.
H. Survey of drivers opinions about work zone.
I. Speed reduction profile of vehicles.
J. Series of passive speed limit signs.
K. Flashing beacons on speed limit signs.

All of the studies were conducted except for E, G, and J. The funding was not sufficient to do these three studies.

This report provides a brief introduction and a summary of findings from each of the studies conducted. Each study is discussed in detail in a separate report (1-10). The following reports were prepared as part of this study:


Data for studies 4 through 8 were collected at the same construction zone on I-57 in central Illinois. 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) (11). The layout of the construction zone and the signs used are schematically shown in Figure 1. To identify different areas within a work zone, the terminology suggested by Lewis (12) is used as much as possible.

The following two reports were also prepared as a part of this study:


It was decided, however, not to publish these last two reports because the reports are based on data for a small sample of flaggers and an unmarked police car. The findings from these two reports are not included here.

It should be noted that in all of the studies, a vehicle was considered to be in free flow traffic when its time headway was greater than 5 seconds. Data only for those vehicles in free flow traffic are used for speed reduction evaluation.
Figure 1. Work zone signs on SB I-57 during speed reduction studies

NOT TO SCALE
2. EVALUATION AND SUMMARY OF STUDIES IN SPEED CONTROL METHODS IN WORK ZONES

As a part of a study on speed control methods in work zones, an extensive literature survey of publications related to speed control in work zones was conducted to identify previous studies and to utilize their findings in planning future research activities. This report contains important findings from previous studies on work zone speed control techniques. It does not include the findings from ongoing research projects at the University of Illinois. Reports and publications on the effects of several work zone speed control devices are reviewed. Summaries of these studies are included in the report. The effects of speed control treatments on speed and traffic flow are evaluated. The evaluation is based on the findings of previous literature and experiences with each speed control method. The evaluation and results of the speed reduction techniques are discussed in the following categories:

(1) Experiences with treatment.
(2) Effects of treatment on speed.
(3) Effectiveness of treatment.
(4) Comments about treatment.

The experiences with treatment category contains a brief description of the conditions under which a treatment was applied. The ability of a treatment to reduce the speeds of vehicles was considered in evaluating the effects of the treatment on speed. The effectiveness of a treatment is evaluated in terms of performance continuity and its impact on speed reduction. In the comments category, factors such as the effect of the treatment on traffic flow or safety and other factors relevant to the treatment are included.

In this report the following speed reduction treatments are included:

1. Flagging.
2. Lane width reduction.
3. Law enforcement.
5. Rumble strips.
6. Flashing beacons.

Rumble strips and flashing beacons had limited applications in work zones, and were used mostly in urban areas or under low speed conditions. Therefore, the results of the experiences may not be applicable to high-speed traffic conditions.
3. EVALUATION OF A RADAR-ACTIVATED HORN SYSTEM FOR SPEED CONTROL IN HIGHWAY MAINTENANCE OPERATIONS

Introduction

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. The system was carried by a pickup truck following the striping crew. 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 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, and 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.

Summary of Findings

The data for all three groups indicated similar decreasing relationships between the average speed reduction and the detection distance before the horn. The average speed reductions at a location 1000 ft. before the horn, although based on limited data points, were less than the reductions at locations 750 ft. or at 500 ft. before the horn. The maximum average reductions for the horn activated and the horn not activated cases were at a location 750 ft. before the horn, whereas for the control group it was at a point approximately 500 ft. before 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 carrying the horn, 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 trend similar 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 mph 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 2 to 4 miles per hour 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 factors, 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.

Recommendations

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, the 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.
4. SURVEY OF DRIVER'S OPINION ABOUT WORK ZONE
TRAFFIC CONTROL ON A RURAL HIGHWAY

Introduction

Motorists’ understanding of traffic control plans (TCP) and their perception of problems in work zones may be different from that of an engineer who prepares the plans. Understanding problems from the drivers’ perspective would be helpful in preparing more effective traffic control plans. A survey instrument was designed to solicit input from drivers right after traveling through a work zone. The survey questionnaire was designed to analyze drivers’ understanding of the work zone traffic control plans, interpretation of work zone messages, reaction to given messages, perception of problems, and their possible solutions. The survey form had 30 questions and asked for suggestions or comments to increase safety and traffic flow efficiency in work zones.

The data was collected at a rest area located about 2 miles south of a construction zone on I-57. The drivers who stopped at the rest area after going through the construction zone were surveyed. The drivers went through several miles of one-lane construction zone before reaching the rest area. The speed limit on I-57 outside of the construction zone was 65 mph for cars and light trucks, and 55 mph for heavy trucks. The speed limit in the construction zone was 45 mph for all vehicles when work was in progress. A regulatory 45 mph speed limit sign, with two small flashing beacons mounted on the signs to indicate construction work in progress, was in effect during work hours. The type of construction occurring on the southbound lanes was asphalt overlay, with one of the lanes closed and the other lane open to traffic. Plastic barrels were used to delineate the construction area during daytime. There was at least one flagger in the work zone using a STOP/SLOW paddle to slow down traffic. The traffic volume in the construction zone was light (about 400 vehicles per hour). The Average Daily Traffic (ADT) in this section of I-57 is about 14,500 vehicles, with 17% large trucks.

The data was collected on 11 weekdays, during the daytime, between September 18 and October 4, 1989 while the construction crew was working on the road. A total of 441 motorists who had just driven through the construction zone were surveyed. After deleting the incomplete and inconsistent responses, a total of 400 remaining surveys were used for analysis.

Summary of Findings

The survey indicated that most of the drivers paid more attention to the messages given by the construction signs than the signs on the freeway. The majority of drivers, 77.3%, responded that they paid more attention to the work zone signs after entering the work zone. About 20% said that they paid the same amount of
attention as before.

A large percentage of drivers saw the flagger and correctly understood the flagger's message (There was at least one flagger in the work zone using a STOP/SLOW paddle to slow traffic). About 82.7% of the survey participants replied that they saw the flagger in the work zone. However, 14.3% said they did not see a flagger in the work zone. Of the drivers who saw the flagger, 87.9% correctly interpreted the flagger's message (proceed with caution and slow down). Zero percent of the drivers said they did not understand the message. However, 3.3% interpreted the message as "proceed with caution but do not slow down," and 2.5% did not remember what the message was. Among the drivers who saw the flagger and correctly interpreted the message, 92.1% reduced their speed if the flagger was asking them to do so. However, 6.2% (18 drivers) did not reduce their speed even though they knew the flagger was asking them to do so. None of these 18 drivers was driving a large truck. Seven out of these 18 drivers knew they were speeding. Twelve out of the 18 drivers thought their speed was safe for the conditions.

The survey indicated that most of the drivers decreased their speed as they saw a flagger, regardless of interpretation of the flagger's message. Eighty nine percent slowed down, 7% did not reduce their speed, and 4% did not remember or did not reply. However, it is not known whether or not the reduction brought their speed to the posted speed limit level.

The signs to move the drivers from the closed lane to the open lane seemed to be adequate. Almost all of the drivers had enough time to move to the open lane without making a late merge. It was observed that most of the drivers moved to the open lane closer to the first arrow board. Relatively low traffic volume and use of two arrow boards before the taper provided a smooth lane change and prevented the drivers from making a forced merge near the taper.

The survey indicated that the regulatory speed limit signs were noticed by most of the drives. A large percentage of drivers, 86.7%, responded that they saw the speed limit signs, 4.8% did not see them, and 8.5% did not remember or did not reply. Even the flashing lights mounted on the speed limit signs did not get the attention of about 1/8 of the drivers. Most of the drivers (90.2%) who saw the speed limit signs remembered the speed limit correctly. However, 7.8% of the drivers remembered the speed limit incorrectly, and 2% of them did not reply or did not remember it. About 6.3% incorrectly said that the speed limit was 40 mph or less.

The survey results indicated that the drivers waited to see the speed limit signs in the work zone before reducing their speed. About 91.4% of the drivers reduced their speed after seeing the speed limit signs. Only 6.1% did not reduce their speed after seeing the speed limit signs. Those drivers were either traveling at the speed limit or did not feel they should do so. About one-third of the drivers knew that their speeds were greater than the posted speed limit and about 59% said their speed was not greater than the posted speed limit. About 94.2% of the speeding drivers
felt that their speed was safe enough for the conditions in the work zone. However, 4.4% said their speed was not safe for the construction zone, but continued to drive faster than the speed limit anyway.

The survey results indicated that a majority of the drivers were aware of the speed limit in the work zone, but did not comply with it. Over three-fourths of the drivers said the speed limit in the work zone was about right. About 17% said it was too low, and 3% said it was too high. Even though 78.5% of the drivers said the posted speed limit was about right, only 59% drove at or below this speed limit. Similarly, only 17% said the speed limit was too low, but 34% drove faster than the speed limit. Considering that 87% of the drivers saw the speed limit signs and 90% of them correctly remembered the speed limit, about one third knowingly traveled faster than the speed limit.

The work zone signs seemed to convey a clear message to 93.5% of the motorists and guide them comfortably through the work zone. About 3.5% said that the signs in the work zone did not provide a clear message, and a small percentage of drivers, 4.3%, responded that the signs did not provide enough information. About 93% of the drivers said that the signs were not confusing, but 4.8% replied that one or more signs were confusing to them.

The drivers' responses seemed to indicate that the posted speed limit was unclear to several drivers. The confusion was, perhaps, due to presence of the freeway 65 mph speed limit sign which was not covered. There was not an agreement among the drivers on description of the "confusing" signs.

The survey indicated that the number of signs in the work zone was not excessive, as indicated by 93% of the drivers. Only 4.3% of the drivers said that there were too many signs. Almost all of the drivers (95.5%) were able to read all the signs in the work zone. Only 2.3% could not read all of the signs.

The drivers' opinions about "hazard" and "comfort" in the work zone were mixed. Nearly half of the drivers (54%) said that they found going through the work zone to be more hazardous than non-work zones, but 42.3% disagreed with this group.

The driving conditions in the work zone were described as comfortable by three fourths of the drivers. However, about 21.7% said the driving conditions in the work zone made them uncomfortable. Nearly half of them said the reason for discomfort was the presence of workers on the freeway. Signing, lane width, and pavement surface conditions all affected drivers' comfort levels.

**Recommendations**

Drivers suggested that a wider driving lane and a shorter construction zone would increase safety. Some commented that with brighter clothing for workers and fewer workers in the traveled lane, safety would be improved. Drivers also felt that either having the flagger further from the actual work area, or having two
flaggers, one much before the actual work for warning and another just before the actual work to slow the vehicles, would be more helpful. They suggested that dimming the arrow board lights and installing brighter lights on the 45 mph when flashing sign would improve their visibility. Bump signs were requested when pavement surface is too rough. There were complaints about inadequate lighting at nighttime, bumps on traveled lanes, rough shoulders, and rough construction joints. Drivers also wanted more up-to-date information on the construction zone. Some wanted to drive at a higher speed limit if there was no work activity, and some requested stricter enforcement of the speed limit. These are all good recommendations and some of them can be easily done.

This study is the first large scale survey of drivers' opinions immediately after traveling through a construction zone. It has some limitations, such as not matching the speed of the vehicle in the work zone to the response given by the driver. Its findings are limited by the scope of the questionnaire and the shortcomings of the study. The shortcomings of this study need to be addressed in future studies. The speed of vehicles in the work zone should be matched with the response of the driver. In future studies also the data should be analyzed by vehicle type and driver categories (i.e. age, sex, etc.).
5. SPEED REDUCTION EFFECTS OF DRONE RADAR IN RURAL INTERSTATE WORK ZONES

Introduction

This study was conducted to determine the effects of using drone radar (passive or unmanned radar) on vehicle speeds in rural interstate highway work zones. The study consisted of three experiments. Experiment 1 was an exploratory study to evaluate the immediate (less than an hour) effects of transmitting radar signals on the speed of vehicles when motorists were traveling at excessive speeds inside and outside of the work zone. Experiment 1 evaluated the speed reduction effects of drone radar at the beginning of the one-lane section of a work zone (Site 1). Site 1 was located in the northbound approach of I-57 just south of Champaign, Illinois. Data were collected at two locations. The first location, Station 1, was outside of the work zone and the second location, Station 2, was shortly after the end of the lane closure taper where only one lane was open.

The second and third experiments evaluated the effects of one and two radar guns, and the lasting effect of continuous radar signal transmission at two locations within a work zone. Experiment 2 was conducted for a longer period of time (a few hours) to evaluate the effects of using one drone radar, while Experiment 3 evaluated the effectiveness of using two drone radar and the lasting effects of radar transmission on vehicle speeds. Two radar guns were used to increase the perceived "threat" of police in the work zone and to make it difficult for the drivers to find out the location of and who was activating the radar. The assumption was that if drivers could not find out whether it was police or drone radar, they might consider the radar as a threat and maintain lower speeds.

Experiments 2 and 3 were carried out in a work zone on the southbound approach of Interstate 57 near Mattoon, Illinois (Site 2). Data were collected at three stations. Station 1 was outside of the work zone. The other two stations were inside of the work zone – one was before the work space and the other after it. At Site 2, data were collected for the following three conditions:

A) Control or base condition – no radar used.
B) 1 Radar treatment – one radar gun continuously activated near Station 2 (Experiment 2).
C) 2 Radar treatment – two radar guns simultaneously and continuously activated, one near Station 2 and the other near Station 3 (Experiment 3).

The 2 Radar treatment was divided into three one-hour time periods. This method was used to examine the lasting effects of drone radar. These time periods are referred to here as Intervals I, II, and
III, designating the first, second, and third hours, respectively. The data for 1 Radar treatment were not divided into two time intervals because the number of observations would have become small, particularly for trucks.

On both sites, traffic data were collected when standard IDOT traffic control plans were used and when the drone radar was added to the standard plans. In the study sites, the highway has two lanes in each direction. One lane in each direction was closed during the construction period. The speed limit outside of the construction zone was 65 mph for cars and 55 mph for heavy trucks (over 4 tons), but inside the work zone the speed limit was 45 mph for all vehicles. The regulatory 45 mph work zone speed limit was in effect when two small yellow lights, mounted on top of the speed limit sign, were flashing.

At Site 2, the construction crew was working on the bridge over Route 16 until the end of Interval II. At the beginning of Interval III all workers left the Route 16 bridge. There were still a few workers sporadically working in the work zone. The flashing light on the speed limit signs were turned off at the end of Interval III.

Summary of Findings from 1 Radar Experiment at Site 1

At Station 1, during the control period, trucks and cars were traveling about 10 mph over their respective speed limits. At Station 2, the average speeds of cars and trucks were 18.8 and 13.5 mph, respectively, over the speed limit. This drone radar experiment resulted in net speed reductions of 8.0 mph on cars and 9.8 mph on trucks. These reductions were statistically and practically significant. The percentages of cars and trucks exceeding the speed limit at Station 2 decreased by 9% and 23%, respectively, during 1 Radar treatment compared to the control period.

Although this drone radar experiment resulted in net speed reductions of about 8 mph for cars and nearly 10 mph for trucks, the results have to be interpreted considering the following factors. (1) The net speed reductions are high because vehicles were traveling faster than the speed limits at points both outside and inside of the work zone. As a result, the speeding drivers may have been more concerned about police threat than if they were traveling at the speed limit. (2) The net reductions may not reflect the long term effects of drone radar since the results are based on data for a very short time period. (3) The location of Station 2 was 850 ft. from the end of the lane closure taper. This point might not reflect the speed further inside the work zone. (4) The net reduction for trucks is computed based on a small sample of drivers that traveled in the work zone during the short time that the radar was activated. The long-term reductions are less likely to be so high.

From 1 Radar Experiment 1 at Site 1, it was concluded that in a very short period of time the drone radar was effective in reducing speed at the beginning of a one-lane section when the
average speed of traffic was high outside of the work zone. This radar experiment simulated a short-term maintenance job where the crew spent less than an hour in one location. Because of the limitations of Experiment 1, two other experiments (Experiment 2 and 3) were conducted to address some of the aforementioned shortcomings.

Summary of Findings From 1 Radar Experiment at Site 2

The results indicated that using one radar gun at this site did not produce additional reductions on the average speed of cars and trucks. The effectiveness of one drone radar at Site 2 was not as significant as that at Site 1. One explanation for this difference is that the cars and trucks were going at much lower speeds than those at Site 1. At Station 2, the average speed of cars was several mph greater than the speed limit, but the average speed of trucks was only slightly over the speed limit. Thus, the drivers may not have felt the need to slow down.

Another reason may be due to the duration of the radar transmission. Time period for Site 2 was about three times longer than that of Site 1 and the drivers had enough time to figure out the location of and who was activating the radar. In fact, within half an hour some of the drivers were aware that there were no police present in the work zone, and they may have not been threatened by the radar transmission.

The changes in the percentages of vehicles exceeding the speed limits during the treatment compared to the control data were relatively small. The decreases were 7%, 4%, and 0% at Stations 1, 2, and 3, respectively, for cars, and 1%, 5% and -1% (an increase) for trucks. Similarly, the changes in the percentage of vehicles exceeding the speed limits by more than 10 mph were negligible for cars, and in the order of 6-8% for trucks. The changes were 1.3%, -3.6%, and -2.8% for cars, and 6.1%, 5.5%, and 8% for trucks at Stations 1, 2, and 3, respectively.

Summary of Findings from 2 Radar Experiment at Site 2

The results indicated that, in general, there were additional speed reductions due to activating two radar guns in the work zone. The additional speed reduction effects were consistent in trucks, but not in cars. Trucks invariably showed a net speed reduction when the radars were activated. Trucks reduced their speed by 1.2-3.2 mph at Station 2, and by 2.9-5.8 mph at Station 3 due to activating two radar guns. In 5 out of 6 cases for the 2 Radar experiment, trucks showed significant net speed reductions. The results indicated that the effects of drone radar did not diminish in trucks over time. Even after three hours, truck drivers did not ignore the radar signals because they could not figure out whether it was police or drone radar. The drivers decreased their speeds since they were not sure if it was drone radar.
Cars showed net reductions of 0 to 1.2 mph at Station 2, which were not statistically significant. However, at Station 3 cars showed net reductions of 1.2-2.9 mph, which were significant for Intervals I and II. Overall, cars showed significant net speed reductions in 2 out of 6 cases. One reason the drone radar was not effective on cars and was less effective on trucks during Interval III might be due to absence of crew over the route 16 bridge during Interval III. Another reason the drone radar was less effectiveness on cars may be that car drivers do not utilize CB radios and radar detectors as much as truck drivers do. Thus, car drivers may not have been aware of the radar transmission.

The differences in the percentage of vehicles exceeding the speed limits during 2 Radar treatment and the Control period presented different trends for each station. At Stations 1 and 3, there were not significant reductions related to the use of radar. However, at Station 2, cars and trucks showed considerable reductions which decreased over time. The reductions were 12%, 7%, and 2%, for cars and 38%, 18%, and 0% for trucks in Intervals I, II, and III, respectively.

The percentage of vehicles exceeding the speed limits by more than 10 mph in 2 Radar treatment, compared to Control data, did not decrease at Station 1, except for the trucks in Interval I. However, at Station 2, there were noticeable decreases for cars in Interval I and for trucks in Intervals I and III. Even higher reductions were obtained at Station 3. The reductions were 21%, 20%, and 4% for cars and 36%, 40%, and 40% for trucks in Intervals I, II, and III, respectively.

**Recommendations**

Drone radar may be used effectively to reduce the speed of fast-moving vehicles which have a radar detector. However, the use of drone radar over longer periods of time diminishes its effectiveness, because the drivers find out that it is not police radar. Therefore, drone radar can be most effective in short periods of time when drivers have not identified the radar. The number of radar devices used directly affected the driver's response. The location of radar-transmitting stations should be selected to provide maximum threat of police presence and should not be easily identifiable by drivers. Drone radar should be used in conjunction with police enforcement, so drivers are kept off-balance as to when the radar is real and when it is drone. The drivers should not be able to conclude that the signals are coming from drone radar.
6. SPEED REDUCTION EFFECTS OF CHANGEABLE MESSAGE SIGNS IN A CONSTRUCTION ZONE

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 CMS 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). 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).

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 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.

Experiment 1 - One CMS in Advance of Work Zone

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. Data were collected at Station 1A and Station 2A. Station 1A was 3600 ft. before the CMS, but Station 2A was 1100 ft. after the CMS. 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.
Experiment 2 - One CMS Inside the Work Zone

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 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 for Experiments 2 and 3 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. past Station 1, and 900 ft. past the first CMS. The third location, Station 3, was located over two miles past Station 2, and 1000 ft. past the second CMS.

Experiment 3 - Two CMSs Inside of the Work Zone

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. The CMS displayed the following two alternating messages "WORKERS AHEAD" and "SPEED LIMIT 45 MPH." Each message was displayed for 2 seconds. Data was collected on the southbound lane of I-57 at the same three stations used in Experiment 2.

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. 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%.

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.

In experiment 2, cars generally traveled faster than trucks, even though the speed limit was the same for both types of vehicles. 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. In general, the percentages of vehicles with excessive speeds decreased, except for trucks at Station 2, when the CMS was displaying the messages.

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. 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. 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 dependent, 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.
7. EFFECTS OF POLICE PRESENCE ON SPEED IN A HIGHWAY WORK ZONE: CIRCULATING MARKED POLICE CAR EXPERIMENT

Introduction

The average speed of free flow traffic in construction zones often exceeds the posted speed limit. Speeding motorists slow down when they encounter a police car patrolling the area or when they perceive that the threat of getting a speeding ticket exists. This study examines the effects of police presence in a construction work zone on speed of vehicles and determines the "halo" effects (lasting effects when police are gone) of police presence on vehicular speed. The Illinois Department of Transportation (IDOT) had hired an off-duty police officer to patrol the work zone. The officer stayed in his car and actively enforced the speed limit laws.

The study is divided into two major parts:

1. The first part evaluates the effects of police presence on the average speed, speed distribution, percentage of fast-moving motorists, and speed reductions that it may cause on cars and trucks.

2. The second part determines the halo effects of police presence on the travel speeds of cars and trucks inside the work zone.

Data for part "a" were collected with police in the work zone (treatment data) and without police (control data). The control data were collected on the day that no police officer was in the work zone and drivers faced the usual traffic control devices used in lane closures on highways. The treatment data were collected on another day when a circulating marked police car patrolled the work zone and issued tickets to speeding motorists. During the treatment day, speeds were affected by the presence of a circulating police patrol inside the work zone. Police remained in the area for 4 hours, from 11 am till 3 pm. Data for part "b" were collected immediately after police left the area.

Police presence in a work zone is an effective way of slowing down the speeding motorists, but it becomes very expensive to have a law enforcement officer in every work zone. A police officer stationed at one point would significantly increase the speed limit compliance at that location; however, the effects would be limited to a smaller area. On the other hand, a circulating police car would impact a larger area, but it may have less overall speed reduction effects. Some drivers with citizens band (CB) radios communicate police presence in the work zone and select their speeds accordingly.

Data were collected in a work zone in the southbound direction of I-57, near Mattoon, in Coles County, Illinois. The construction
zone had an approximate length of 3.5 miles. The highway has two lanes per direction, but one lane was closed in each direction during the construction period. The construction site mainly consisted of bridge deck reconstruction and some shoulder and ramp improvements. There were approximately 5 to 10 workers behind safety shaped (jersey) construction barriers. The construction crew was equipped with a large crane and some small tractor-type equipment. The weather conditions were hot and sunny with no rain during the two-day data collection period. The construction zone traffic control plan was one of IDOT's standard plans for lane closures on multi-lane highways. The speed limits outside of the work zone were 65 mph for cars and 55 mph for trucks. However, a regulatory 45 mph speed limit was in effect inside the construction zone for all vehicles when flashing beacons on the speed limit signs were turned on.

Data were collected for control and treatment conditions at three speed stations. The first station, Station 1, was located outside the traffic control zone where two lanes were open to traffic. The second and third stations, Stations 2 and 3, were located inside the work zone where only one lane was open to traffic. While the treatment data were being collected, the marked police vehicle circulated within the work zone and patrolled both the northbound and southbound directions of the highway. On the treatment day, the speed limit was actively enforced and the police officer issued 12 speeding tickets.

In addition to the speed data, the conversation among drivers, police radar usage in the work zone, and traffic flow conditions at the speed stations were also monitored. Two CB radios were used to monitor the conversations among drivers. A radar detector was used to monitor how often the police officer was using radar. Furthermore, Stations 2 and 3, as well as the activities over the Route 16 bridge, were monitored to record any unusual behavior that might disturb the normal flow of traffic near the stations.

The vehicles in a traffic stream were classified into free flow and platooning. A vehicle was considered to be in free flow traffic when its time headway was greater than 5 seconds, otherwise it was considered to be a member of a platoon. A vehicle in the free flow traffic could travel at its desired speed because it was not blocked by the vehicle in front of it. However, a platooned vehicle had to follow the leader of the platoon; thus, its speed was influenced by the speed of the lead car. The sum of free flow and platooning vehicles comprised the total flow traffic.

Speeds of free flow and total flow traffic were compared to assess the difference between the two. This difference is important because police presence affects speed of all vehicles, but only the free flow traffic is used to assess the police presence. A platooning vehicle is blocked by the leader of the platoon and often has to travel below its desired speed. It is possible that a platooning vehicle may voluntarily reduce its speed due to the police presence and still remain in the platoon. Although the speed reduction on a platooning vehicle may not be voluntary, it does contribute to the overall speed reduction and
therefore may increase traffic safety.

The platooning traffic should not be used for police presence evaluation because, for a platooning vehicle, it is very difficult to separate the voluntary speed reduction from the one imposed by the leader of the platoon. In this study only the free flow traffic data are used for statistical analyses.

The effect of police presence in the construction zone may last beyond the actual time the police are present in the work zone. Traffic moves at a reduced speed when police are present in the work zone and this trend of traveling at the reduced speed may continue for a time period immediately after the police departure from the work zone. Furthermore, drivers with a citizen band (CB) radio may communicate with other drivers regarding police presence in the work zones.

Some drivers may still take the "threat" of police presence seriously and may travel at reduced speeds after police leave the work zone. Thus, the police presence may have halo effects on vehicle speeds. If the halo effect is sustained, one police officer may control a few adjacent work zones without a significant loss in his/her effectiveness on speed reduction.

Conclusions

The statistical analysis of the data collected indicated that police presence (a circulating marked police car) in the highway work zone was effective in reducing the average speeds and percentages of fast moving cars and trucks. The average speeds of the cars inside the work zone were 4.3-4.4 mph lower when police were patrolling the work zone compared to the no-police condition. Similarly, trucks presented speed reductions of 4.3-5.0 mph due to police presence. The percentages of cars and trucks exceeding the speed limit decreased by 14% and 32%, respectively, at a location before the work space. However, after passing the work space, cars and trucks increased their speeds.

The analysis of the halo effects of police presence (lasting police effects) indicated significant lasting police effects on trucks, but not on cars. During a one-hour period immediately following the police departure, the average speed of cars increased by 2.4-3.0 mph, but for trucks the increase was only 0.3-0.4 mph. The results indicated that cars significantly increased their speeds in the work zone after police left the area, but trucks kept traveling at the reduced speed. Although cars increased their speeds after police left the work zone, their speeds were still lower than those for the control data which were collected on a day when police were not in the work zone. These results indicated that the speed reduction effects of police on trucks did not diminish right after the police left the work zone, but tapered off for cars. For trucks, the speed reduction effects of police presence inside the work zone lasted for at least one hour immediately after the police left.
Recommendations

The presence of a circulating police car inside the work zone was effective in reducing the speed of cars and trucks. The speed was reduced not only near the police car, but also throughout the work activity area. It is recommended to continue using police officers for speed control in work zones. Although drivers with CB radios communicated the location and presence of police, the communication did not seem to diminish the effectiveness of police presence on trucks. After the police left the work zone, truck drivers still took the threat of police presence seriously and traveled at reduced speeds. Since the halo effect was sustained for trucks, one police officer can be used to control a few adjacent work zones without a significant loss in his/her effectiveness on speed reduction.
8. EVALUATION OF WORK ZONE SPEED LIMIT SIGNS
WITH STROBE LIGHTS

Introduction

Regulatory 45 mph speed limit signs are placed in Illinois' rural interstate construction zones. The construction zone speed limit sign used in Illinois consists of a regulatory 45 mph speed limit sign with two small strobe lights and two orange colored plates added to it. The wording on the orange plates indicates that when the lights are flashing the speed limit is 45 mph. The flashing light are turned off when the crew is not working. The speed reduction effects of the signs on cars and trucks were determined at two locations within the work zone. Three different data sets were used for this analysis.

The data were collected for 3 days which are defined as Data Sets 1 through 3. Each data set has two time periods. In one time period the strobe lights were turned on, and in the other time period the lights were turned off. There were three data collection stations: Stations 1, 2 and 3. The time periods were selected such that there would be no other factors (e.g. a police presence at work zone) that could influence the drivers' behavior.

The work zone was located on I-57 near Mattoon, Illinois, and was about 4 miles long. The construction crew were mainly working on two bridges (bridge deck repair). Other work zone activities involved shoulder improvements and other minor repair work. The Illinois standard traffic control plan for one lane closure on a rural highway was used in this location. The highway had two lanes per direction with one lane closed and the other lane open to traffic. The average daily traffic on this section of I-57 is 11,800 vehicles.

Conclusions for Data Set 1

The results from Data Set 1 indicate that when the lights on the speed limit signs were flashing, the average speed of cars was reduced by 3.7-5.9 mph, and the average speed of trucks by 1.3-3.3 mph inside the work zone. The lights on the speed limit signs did not significantly reduce the average speed of trucks near the beginning of the one lane section, but did reduce it further down the line in the work zone. Thus, when the lights were flashing the cars traveled about 3.7 mph slower before reaching the work space, and 5.9 mph slower after passing the work space than when the lights were off. However, trucks only traveled 3.3 mph slower after passing the work space. In general, the percentages of vehicles with excessive speeds in the work zone decreased when the lights were flashing.
Conclusions for Data Set 2

The results from Data Set 2 indicated that when the lights on the speed limit signs were flashing, cars and trucks reduced their speeds. The strobe lights were effective in reducing the average speed of cars by 1.9-7.0 mph, and the average speed of trucks by 1.8-5.8 mph inside the work zone. The strobe lights on the speed limit sign not only reduced the average speed of vehicles near the beginning of the one lane section, but also reduced the speeds further down the line in the work zone. Thus, when the lights were flashing the vehicles traveled about 1.8-1.9 mph slower before reaching the work space, and 5.8-7.0 mph slower after passing the work space. Furthermore, when the lights were flashing, the percentages of vehicles with excessive speeds inside the work zone decreased.

Conclusions for Data Set 3

The results from Data Set 3 indicate that the strobe lights on the speed limit signs were effective in reducing the average speed of cars by 4.9 - 7.1 mph, and the average speed of trucks by 2.9 - 6.0 mph inside the work zone. The strobe lights on the speed limit sign not only reduced the average speed of vehicles near the beginning of the one lane section, but also reduced it further down the line in the work zone. Therefore, when the lights were turned on, cars and trucks traveled about 4.9 and 2.9 mph slower before reaching the work space, and 7.1 and 6.0 mph slower after passing the work space. In general, the percentages of vehicles with excessive speeds decreased when the lights were flashing.

Summary of Findings

The results from Data Sets 1-3 indicated that the average speed of cars was reduced by 1.9-7.1 mph and that of trucks by 1.3-6.0 mph when the strobe lights on the speed limit signs were flashing. The speed reduction effects were, in general, more pronounced on the cars than on the trucks. Cars and trucks showed net speed reductions before reaching the work space as well as after passing it. The reductions at the location past the work space were 2-3 times more than the reductions at the location before the work space. Cars reduced their speeds, on the average, by 1.9 to 4.9 mph before and by 5.9 to 7.1 mph after the work space. Similarly, the speed reduction for trucks was 1.3-2.9 mph before and 3.3-6.0 after the work space. In general, the percentages of vehicles with excessive speeds in the work zone decreased when the lights were flashing.
9. SPEED REDUCTION PROFILES OF VEHICLES IN A HIGHWAY CONSTRUCTION ZONE

Introduction

Slowing down the speeding motorists in construction zones is a safety concern for highway officials. Most drivers slow down when they perceive a potential hazard on the road, such as the presence of crew or large equipment near the traveled lane. It is not known where drivers slow down in a work zone, and how their speeds fluctuate throughout the work zone. For example, do faster drivers reduce their speeds more than the slower ones? In order to respond to questions such as this, speed profiles of vehicles in the work zone are needed. From the speed profile data, velocity of a vehicle at different locations along the work zone can be obtained and the speed reduction effects of various traffic control devices and roadway features may be determined. The information from the speed profile study will help to understand drivers' behavior in work zones and to select more efficient and effective methods of traffic control.

This study was conducted to determine speeds of vehicles at different locations within a work zone in order to plot their speed profiles. The field experiment consisted of obtaining video images of vehicles as they traveled through the construction zone. The vehicles were video taped from the time they entered a 1.5-mile long study section until they left it. The speed profile data for 208 vehicles were collected, and a speed profile for each vehicle was generated.

A vehicle was labeled as "influenced" if it was slowed down by another vehicle in front of it, otherwise it was labeled as "uninfluenced." The uninfluenced vehicles were in free flow traffic traveling at their desired speed in the work zone. The findings of this study are based on the speed characteristics of the uninfluenced vehicles. The uninfluenced vehicles were further divided into two vehicle groups - the Autos group and the Trucks group. Autos included passenger cars, vans, and pickup trucks. Those vehicles in the Truck group are of the tractor semi-trailer type. Out of 208 vehicles, 57 vehicles were tagged as influenced vehicles. The remaining 151 vehicles were labeled as uninfluenced. There were 102 Autos and 49 Trucks.

The construction zone was located on a rural section of Interstate 57 in Coles county near Mattoon, Illinois. The highway has two lanes per direction, but one lane in each direction was closed because of the construction. The work zone was about 3.5 miles long. The study section, where the vehicles were video taped, was about 1.5 miles in length and was within the work zone. The construction work was mainly repair of two bridge decks, one over State Route 16 and one about 2.5 miles to the south of Route 16. Other construction activities included patching, overlay, and shoulder reconstruction on the ramps of Route 16 and I-57.
Throughout the construction zone, there are traffic control signs and roadway features that may influence speed of a vehicle. An Influence Point (IP) is defined as a location within the construction zone that may have such a sign or roadway feature. The locations of IPs and distances between them are given in Table 1. Thirteen IPs, labeled "a" through "m", were identified in this study (see Figure 2). The speed of a vehicle at these Influence Points was determined using the speed profiles.

Table 1. Influence Points and their distances from the beginning of the study section

<table>
<thead>
<tr>
<th>INFLUENCE POINTS</th>
<th>LOCATION IN WORK ZONE</th>
<th>DISTANCE (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Beginning of the taper</td>
<td>600</td>
</tr>
<tr>
<td>b</td>
<td>End of the taper</td>
<td>1600</td>
</tr>
<tr>
<td>c</td>
<td>500 ft Before 1st speed limit signs</td>
<td>2100</td>
</tr>
<tr>
<td>d</td>
<td>At 1st speed limit signs</td>
<td>2600</td>
</tr>
<tr>
<td>e</td>
<td>500 ft After 1st speed limit signs</td>
<td>3100</td>
</tr>
<tr>
<td>f</td>
<td>Near the end of upgrade section</td>
<td>4300</td>
</tr>
<tr>
<td>g</td>
<td>1200 ft before Rt. 16 bridge</td>
<td>4800</td>
</tr>
<tr>
<td>h</td>
<td>600 ft before Rt. 16 bridge</td>
<td>5400</td>
</tr>
<tr>
<td>i</td>
<td>At Rt. 16 bridge</td>
<td>6000</td>
</tr>
<tr>
<td>j</td>
<td>500 ft after Rt. 16 bridge</td>
<td>6500</td>
</tr>
<tr>
<td>k</td>
<td>1000 ft after Rt. 16 bridge</td>
<td>7000</td>
</tr>
<tr>
<td>l</td>
<td>Before 2nd speed limit signs</td>
<td>7900</td>
</tr>
<tr>
<td>m</td>
<td>Second speed limit signs and end of the study section</td>
<td>8300</td>
</tr>
</tbody>
</table>

Knowing the nature and extent of the speeding problems in a work zone would help to select appropriate counter measures which may result in more effective traffic control plans. The locations at which the drivers slowed down or speeded up are the critical points in a construction zone. Knowing these points would help to place the signs at the appropriate locations. Traffic control plans should be carefully prepared in order to obtain a higher level of compliance from the drivers.

Drivers travel at different speeds at the beginning of the lane closure taper, and their initial speeds may influence the speeds they will maintain in the work zone. It is attempted to determine how the initial speed of a vehicle would influence its speed in the work activity area. In other words, what would the effects of the speeds at the beginning of the lane closure taper be
Figure 2  Plan, profile, location of influence points and speed stations
on the speeds inside the one-lane section of the work zone?

Conclusions

The speed reduction profile of each vehicle was obtained from the speed profiles. The findings of this study are reported in the following four sections.

Speed Characteristics

The average speeds of Autos and Trucks were 5-18 mph and 1-12 mph, respectively, over the work zone speed limit. The average speeds of Autos were about 4-7 mph higher than those of Trucks. Auto and Truck drivers decreased their speeds to the lowest level near the work space, but after passing it they increased their speeds to the higher levels they had before the work space. The percentage of vehicles exceeding a speed level decreased as they approached the work space (bridge), but after passing it the percentage increased to the higher levels found before the work space. Although the percentage of vehicles exceeding the speed limit at the work space was the lowest compared to other locations, nearly 65% of Autos and 47% of Trucks traveled faster than 45 mph at this location.

Driver Categories

Four categories of drivers were identified based on the speed reduction profiles. The drivers in different categories showed distinct speed reduction patterns. The speed profiles for different groups are shown in Figures 3 through 8. The speed profiles for Autos and Trucks indicated that they have similar speed reduction patterns in the work zone. About 61% of the drivers reduced their speeds considerably after passing the first work zone speed limit signs, which were located at the beginning of the one-lane section of the work zone (these drivers comprised Category 1).

Category 1 was further divided into three sub-categories. Approximately 24% of the drivers were in Category 1.1, which represents the drivers who decreased their speeds near the first work zone speed limit signs and had further speed reductions at the work space (bridge). The latter speed reduction often was greater than the former reduction. About 22% of the drivers slowed down considerably at the first speed limit signs and at the bridge, but between these two points increased their speeds (Category 1.2). Their speed profiles resembled a "W". Nearly 15% of the drivers reduced their speed around the first speed limit signs and kept traveling at that reduced speed until they passed the bridge (Category 1.3).

Categories 2-4 included 39% of the drivers. Nearly 15% of the
drivers did not reduce their speeds until they neared the location of construction activities (Category 2). About 11% of the drivers traveled at constant high speeds and did not reduce their speeds considerably in the work zone (Category 3). The profiles for the remaining drivers did not indicate a common pattern (Category 4).

The proportions of Trucks and Autos in the driver categories were similar except in Categories 1.3 and 2. The percentage of Truck drivers who reduced their speeds around the first speed limit signs and kept traveling at that reduced speed until they passed the bridge (Category 1.3) was twice that of the Auto drivers. However, the percentage of Truck drivers who traveled faster than the speed limit and basically ignored the first speed limit sign, but began to slow down when they arrived at the work space (Category 2) was about one half of the percentage of Auto drivers. Thus, appropriate counter measures to increase speed compliance in work zones should mainly be directed to the intended category of drivers.

Speed Reductions

Autos and Trucks, on the average, traveled 3-13 mph and 3-12 mph, respectively, slower inside the work zone compared to their speeds at the beginning of the taper. As drivers traveled further into the work zone the speed reductions first increased, then slightly decreased, and finally reached a maximum value at the bridge. After passing the bridge, the speed continuously increased until vehicles left the study section.

It is important to note that a small percentage of drivers reduced their speeds by large amounts; thus, the speed reduction frequency distribution plots were not bell-shaped, but had a long tail. These shapes must be considered in making statistical inferences about speed reduction in work zones.

Comparisons of speed reductions at different locations before the work space to the reductions at similar locations past the work space indicated that vehicles attempted to reach the speeds they had before the bridge. The speed reductions before and after the first work zone speed limit signs were also compared. The speed limit signs were found to be effective in reducing the average speed of Autos by 3.5 mph, and that of Trucks by less than 3 mph, at a point immediately after the signs.

Speed Groups

The speeds at the beginning of the taper were used to group the vehicles into four speed groups: Fast, Faster, Very Fast, and Fastest moving group. For all speed groups, the average speeds gradually decreased before the bridge and increased after passing the bridge. The maximum reduction in the average speed at different locations increased as the initial mean speeds increased. This trend indicates that, on the average, the vehicles with higher
Figure 3. Typical speed profile for drivers in Category 1.1

Figure 4. Typical speed profile for drivers in Category 1.2

Figure 5. Typical speed profile for drivers in Category 1.3
Figure 6. Typical speed profile for drivers in Category 2

Figure 7. Typical speed profile for drivers in Category 3

Figure 8. Typical speed profile for drivers in Category 4
speeds at the beginning of the taper reduced their speeds more than
the vehicles with lower initial speeds. However, the drivers in
the higher initial speed groups kept higher speeds in the work zone
than the drivers in the lower initial speed groups, even though the
former group had larger speed reductions than the latter group.

Recommendations

The location at which drivers slow down, or speed up, are
critical points in a construction zone. Knowing these points would
help to place the signs at their appropriate locations. It is
recommended that the placement and frequency of the work zone speed
limit signs be examined using the speed reduction pattern of the
vehicles. The measures taken to slow down the drivers in Category
3 who ignored the speed limit signs and the construction activities
may be different from those for drivers in Category 1.

Category 1.3 is an ideal pattern and other drivers should be
encouraged to follow this pattern. Placing additional speed limit
signs between the first speed limit signs and the work space may
persuade the drivers in Category 1.1 to slow down further, and may
discourage the drivers in Category 1.2 from increasing their speed
before the work space. The drivers in Category 1.2 may have
increased their speeds because they perceived that the work space
was too far from the first speed limit signs.

The location of the signs and the length of the section before
the work space should be such that most drivers are encouraged to
follow the speed limit. Since 61% of drivers reduced their speeds
around the first speed limit signs and 75% of all drivers reduced
their speeds near the work space, more speed reduction may be
achieved if the work space is closer to the beginning of the work
zone.

The analysis indicated that location of a speed measuring
station has to be carefully selected because it will affect the
outcome of the measurements. Furthermore, speed distributions, as
well as the mean speeds, should be analyzed in order to obtain more
accurate speed characteristic data. Speed profile data from other
work zones should be used to further validate the findings of this
study.

The data reduction stage should be computerized to reduce the
human resources needed. The video images provide a permanent
record that will reduce the mistakes caused by human or equipment
error. The computational errors of this data collection method are
reasonable. This approach, though time consuming in the data
reduction stage, should be used in future studies.
10. REFERENCES


