SPEED REDUCTION EFFECTS OF DRONE RADAR IN RURAL INTERSTATE WORK ZONES

By

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

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Three experiments were conducted to evaluate the effectiveness of using drone (passive or unmanned) radar guns on vehicle speeds in construction zones. Experiment 1 was an exploratory study to find the immediate (less than an hour) effects of using one drone radar gun. Experiment 2 was conducted for a longer time period (a few hours) to evaluate the effects of using one drone radar gun. Experiment 3 evaluated the effects of using two drone radar guns and their lasting effects on vehicle speeds. Experiment 3 was divided into three one-hour time intervals. This method was used to determine the lasting effects of drone radar. Data analysis included the comparison of mean speeds, speed distributions, percent exceeding a given speed, and net speed reductions. The immediate effects of using one radar gun (Experiment 1) were 8-10 mph speed reductions; however, such reductions should not be considered typical effects of radar signal transmission because of the exploratory nature of Experiment 1. Experiment 2 showed that using a radar gun was not effective in reducing vehicle speeds when drivers knew it was drone radar. Experiment 3 indicated that the use of two radar guns increased the effectiveness of drone radars, since drivers were not sure whether the signals are from a police radar or drone radar. The two radar experiment reduced truck speeds by 3-6 mph and car speeds by 3 mph, and the radar effects did not diminish over time. In Experiments 1 and 3 the percentage of vehicles with excessive speeds inside the work zones decreased when radar signals were transmitted. Furthermore, the decreases in Experiment 3 were sustained over a period of time.
ACKNOWLEDGMENT AND DISCLAIMER

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The contents of this report reflect the views of the authors who are responsible for the facts and 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.
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INTRODUCTION

This study was conducted for the Illinois Department of Transportation (IDOT) 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).

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 (Site 2). 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.

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. The traffic control plans are prepared according to the procedures discussed in the Manual on Uniform Traffic Control Devices (MUTCD) (1). For instance, the traffic control plan for Site 2 is shown in Figure 1. The study sites were located on I-57 in central Illinois. The highway is a four-lane highway, with 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.

Background

Radar guns have been widely used by law enforcement officers to measure the speed of motorists. Warren (2) synthesized the effects of law enforcement on regular highway sections (not work zones) and reported that, in most cases, police enforcement decreased speed by less than 3 mph, but reductions of up to 10 mph were also reported. Pigman et al. (3) used unmanned radar at two high accident locations (not in work zones) on I-75 and reported that it was effective in reducing the speed of vehicles traveling
Figure 1. Work zone signs on SB I-57 (site 2) during drone radar study.
at excessive speeds. They reported that the speed of vehicles with radar detectors decreased significantly compared to those without radar detectors. They observed that 42% of trucks and 11% of cars had radar detectors.

Having a police officer in every work zone would be a very expensive speed enforcement option. However, providing an indication of a "threat" of police presence, such as using drone radar, is relatively cheap and may work to alleviate some of the speeding problems in work zones. Richards et al. (4) reported that a stationary patrol car with radar on caused 3 mph more speed reduction than a stationary patrol car in a construction zone on an urban freeway with a 40 mph regulatory speed limit. Ullman (5) reported that radar transmission, without police presence in work zones, reduced the average speed by less than 1.7 mph in 7 out of 8 study sites. Five out of the 7 sites were suburban interstate highway, one was suburban divided highway, and one was rural divided highway. On the eighth site (a suburban interstate highway) a reduction of 4.5 mph was obtained, but this reduction was computed based on a small sample of observations (less than 30 vehicles), so it was not reliable. There have been a very limited number of studies directly dealing with the effects of drone radar on speed in work zones.
The approach used in this study is commonly known as the before and after study with control group. The data collection and data analysis steps are performed according to this method. The following sections describe these steps in more detail.

Data Collection for Experiment 1

The study site was located in the northbound approach of I-57 just south of Champaign, Illinois (Site 1). Data were collected on September 22, 1989 for two time periods. During the first period (control period) no drone radar was used, but during the second period (1 Radar treatment) one radar was used at Station 2. The control data was collected from 1:00-2:00 pm, and the treatment data from 2:15-2:50 pm. 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 location of data collection stations are shown in Figure 2.

The vehicle speeds at each station were collected with mechanical traffic counters. The traffic counters were IRD Traffic Counter and Classifiers (TCC). The counters were programmed to keep a record of individual vehicles. This was ascertained to be more accurate than having the traffic counter sort the data and store them in bins. The regulatory 45 mph work zone speed limit signs were located at the end of the lane closure taper. During the data collection period the flashing beacons on the speed limit signs were turned on.

Data Collection for Experiments 2 and 3

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 using TCC. Station 1 was outside of the work zone. The other two stations were inside of the work zone, as shown in Figure 3. 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 control data were collected from 10:00 am to 12:00 noon on June 12, 1990. Data for the 1 Radar treatment were collected from 1:30 pm to 3:10 pm on June 12, 1990. Data for 2 Radar treatment were collected from 1:40 pm to 4:25 pm on June 11, 1990.
Figure 2: Locations of speed stations and radar gun on northbound I-57 (Site 1)

Not to scale
Figure 3. Locations of speed stations and radar guns on southbound I-57 (Site 2)

Station 3

Radar 2

1 mile

1000 ft

Station 2

Radar 1

3400 ft

2 miles

I-57

Route 16 bridge

NORTH

Not to scale
The 2 Radar treatment was divided into three one-hour (55 minutes) 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.

**Data Reduction**

The raw traffic data collected by the TCC were stored in the internal memory of the unit. Each TCC can store individual records of up to 8,000 vehicles. The data were downloaded to an IBM PC and were stored in an ASCII format. In order to reduce the traffic data to meaningful results, a Fortran program called TRAFFIC was written to perform sorting, classification, and error checking on the raw data. The TRAFFIC program deletes any duplicated entries from the file, separates the data according to lane traveled, computes the headway for successive vehicles in each lane, filters out erroneous data, and separates free flow traffic data from that of platooning vehicles. A vehicle was considered to be in free flow traffic when its time headway was greater than 5 seconds. This study used data only for those vehicles in free flow traffic conditions.

**Data Analysis Approach**

All statistical analyses were performed using a Personal Computer version of the Statistical Analysis System (SAS) software, PC-SAS Version 6.04, (6). A separate statistical analysis was performed for cars and trucks due to the difference in the posted speed limits and the differences found in their respective speed distributions. The two tests used for statistical analysis, the Student's t-test and the F-test, are briefly discussed below.

**Comparing Speed Distributions**

The F-test was used to compare speed variances of two data sets in order to determine whether or not they had equal variances (the shape of the distributions were similar). Equal variances implied that the shape of the distributions were the same. The F-test was performed with a 95% confidence level. The calculated F-value was computed as:

\[
F = \frac{S_1^2}{S_2^2}
\]
where:
\[ S_1^2 = \text{The variance of speeds for data set 1.} \]
\[ S_2^2 = \text{The variance of speeds for data set 2.} \]
The results of the F-test also determined the type of t-test to be used for comparing average speeds. When the distributions of speeds were not the same (unequal variances), an approximate value of \( t \) was used to reflect the difference in the shape of the distributions (7).

**Comparing Mean Speeds**

The t-test was used to compare the average speed of one data set to the average speed of another data set. The t-value was computed as:

\[
\frac{U_1 - U_2}{\sqrt{\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1 + n_2 - 2} \left( \frac{1}{n_1} + \frac{1}{n_2} \right)}}
\]

where:

\( U_1, U_2 = \text{The average speeds for data sets 1 and 2.} \)
\( n_1, n_2 = \text{The number of observations in data sets 1 and 2.} \)

One assumption that was needed in order to use the t-test was that the speed data had a normal distribution. The data used in this study were for free flow vehicles and therefore did not necessarily have a normal distribution. However, the t-test was still viable because of its relative insensitivity to normal distributions (7). Although calculated and approximate t-values for the test were nearly identical, the approximated values were used whenever the distributions had unequal variances.

**Analyzing Net Speed Reductions**

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

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

\[
\text{Net Speed Change at Station } n = (\bar{U}_{nt} - \bar{U}_{nc}) - (\bar{U}_{1t} - \bar{U}_{1c})
\]

Where:

\(\bar{U}_{nt}\) = The treatment mean speed at Station 1.
\(\bar{U}_{nt}\) = The treatment mean speed at Station \(n\), \(n=2\) or \(3\).
\(\bar{U}_{1c}\) = The mean speed for control data at Station 1.
\(\bar{U}_{nc}\) = The mean speed for control data at Station \(n\), \(n=2\) or \(3\).
Description of 1 Radar Experiment at Site 1

At Site 1, one radar was activated near Station 2 for a short period of time. A citizens band (CB) radio was used to monitor the conversation between drivers. The flashing lights on the speed limit signs were on during data collection, and no police were present in the work zone. A research assistant stayed inside a small vehicle parked on the northbound shoulder and activated the radar and monitored the traffic as well. Data were collected for one hour when no radar was used (control data) and for 35 minutes when one radar was used at Station 2. Data were collected at two locations. The first location, Station 1, was outside of the work zone and the second location, Station 2, was located shortly after the end of the lane closure taper.

A small construction crew (4-5 people) with light equipment and a pick up truck was working north of our speed Station 2. The crew moved from one location to another as workers finished minor pavement repair jobs. The crew was far enough from Station 2 and its presence did not cause a noticeable speed reduction at Station 2.

Summary of Findings from Experiment 1

The speed characteristics and net speed reductions for Experiment 1 are discussed in Appendix A. 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 vehicles exceeding the speed limits at Station 1 were practically the same for treatment and control data. However, 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. At Station 1, there were 12% and 9% fewer cars and trucks, respectively, traveling at least 10 mph over the speed limits when the radar was on compared to the control data. However, at Station 2, the reductions were significantly higher as represented by 46% and 54% decreases for cars and trucks, respectively.

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.
Analysis of 1 Radar Experiment at Site 2 (Experiment 2)

Description of 1 Radar Experiment at Site 2

The first experiment at Site 2 was conducted with one radar activated near Station 2. The speed of vehicles was measured at three stations. Two CB radios were used to monitor the conversation among drivers. Stations 2 and 3 were also monitored to record any unusual behavior that might disturb the normal flow of traffic near the stations. The flashing lights on the speed limit signs were on during data collection. Police were not present in the work zone. The construction crew was working on the bridge over Route 16. The research assistants stayed inside a small vehicle parked on the northbound shoulder and monitored the traffic in the southbound direction.

Highlights of CB Monitoring

The study team used a K-band radar gun and activated it at 1:30 pm. The radar was placed in a car parked in the northbound direction facing the traffic on the southbound lanes. CB radios immediately reported the presence of the radar signals. At 1:42 (12 minutes later) drivers were still talking about the radar. They indicated that they had not seen a police car, and some speculated that it was drone radar placed in the work zone. At 1:57 (27 minutes after activating the radar) drivers found out the location of the radar and even described the driver of the car transmitting the radar. The conversation among drivers continued on and off until the radar transmission was stopped. It should be noted that the study team was only able to hear the conversation when the drivers were close to the team. From CB monitoring it became clear that some drivers knew that it was not police radar.

Data Analysis for 1 Radar Experiment at Site 2

This section provides a brief description of speed characteristics and discusses the net effects of using drone (passive) radar in the work zone. Detailed discussions of speed characteristics and percentage of vehicles exceeding a given speed are given in Appendix B for the control data and 1 Radar treatment. The speed characteristics of vehicles during the control period represent the general behavior of drivers traveling in the work zone. Drivers may travel at lower speeds when drone radar is used in the work zone. The information given in this section for speed characteristics during the control period will also be used in the discussion related to the 2 Radar Experiment.
Summary of Speed Characteristics

The average speeds were lower at Station 2 compared to Station 1, but higher at Station 3 compared to Station 2. This speed trend was observed for both cars and trucks (Figures 4 and 5). Summaries of speed statistics for each station in the treatment and control periods by different vehicle types are given in Tables 1 and 2.

The control data showed that car drivers traveled as high as 84 mph outside and as high as 77 mph inside of the work zone. Their average speeds exceeded the speed limit by 3, 9, and 16 mph at Stations 1, 2, and 3, respectively. The percentages of cars exceeding the speed limits were 73%, 96%, and 99% at Stations 1, 2, and 3, respectively. The percentages of cars traveling 10 mph above the speed limits were approximately 6%, 34%, and 80% at Stations 1, 2, and 3, respectively. The percentages of cars exceeding a given speed level are shown in Figure B.1 in the appendix.

Truck drivers traveled as high as 82 mph outside and as high as 72 mph inside the work zone during the control period (Table 1). The average speeds of trucks were approximately 8, 4, and 12 mph higher at Stations 1, 2, and 3, respectively, than the speed limits at those stations. The percentages of trucks exceeding speed limits at Stations 1, 2, and 3 were about 89%, 75%, and 97%, respectively. The percentages of trucks traveling 10 mph above the speed limits were approximately 27.7%, 9.6%, and 68.0% at Stations 1, 2, and 3, respectively. The percentages of trucks exceeding a given speed level are given in Figure B.2.

Data for 1 Radar experiment indicated maximum car speeds of 90 mph outside and 74 mph inside the work zone. The average speeds of cars were 2, 9, and 15 mph over the speed limits at Stations 1, 2, and 3, respectively. Speeding cars constituted 66%, 92%, and 99% of free flow car traffic at Stations 1, 2, and 3, respectively (Table 2). Approximately 4.7% of the cars were traveling higher than 75 mph at Station 1. At Stations 2 and 3, approximately 37.6% and 82.8%, respectively, of the cars were going faster than 55 mph (Figure B.3).

During 1 Radar treatment, trucks were going 7, 3, and 12 mph faster than the speed limits at Stations 1, 2, and 3, respectively. About 88%, 70%, and 98% were speeding at Stations 1, 2, and 3, respectively (Table 2). The percentages going faster than 10 mph above the posted speed limits were nearly 21.6%, 4.1%, and 60%, respectively, at Stations 1, 2, and 3 (Figure B.4).

Net Speed Reductions

The net speed reductions for cars and trucks at Stations 2 and 3 were computed using the procedure described in the Study Approach section. The net reductions are summarized in Table 3 and are discussed in the following sections.
Figure 4. Average speeds for cars at Site 2 - Control vs 1 Radar

Figure 5. Average speeds for trucks at Site 2 - Control vs 1 Radar
### TABLE 1
**SPEED STATISTICS FOR CONTROL DATA AT SITE 2**

<table>
<thead>
<tr>
<th>VEHICLE TYPE</th>
<th>CARS</th>
<th>TRUCKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATION</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>MEAN SPEED</td>
<td>68.3</td>
<td>53.5</td>
</tr>
<tr>
<td>MIN. SPEED</td>
<td>48.0</td>
<td>42.0</td>
</tr>
<tr>
<td>MAX. SPEED</td>
<td>84.0</td>
<td>72.0</td>
</tr>
<tr>
<td>STANDARD DEVIATION</td>
<td>4.87</td>
<td>5.72</td>
</tr>
<tr>
<td>NO OF OBS.</td>
<td>274</td>
<td>193</td>
</tr>
<tr>
<td>% EXCEEDING SPEED LIMIT</td>
<td>73.4</td>
<td>95.9</td>
</tr>
</tbody>
</table>

### TABLE 2
**SPEED STATISTICS FOR 1 RADAR TREATMENT AT SITE 2**

<table>
<thead>
<tr>
<th>VEHICLE TYPE</th>
<th>CARS</th>
<th>TRUCKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATION</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>MEAN SPEED</td>
<td>67.1</td>
<td>53.5</td>
</tr>
<tr>
<td>MIN. SPEED</td>
<td>49.0</td>
<td>35.0</td>
</tr>
<tr>
<td>MAX. SPEED</td>
<td>90.0</td>
<td>69.0</td>
</tr>
<tr>
<td>STANDARD DEVIATION</td>
<td>6.03</td>
<td>5.83</td>
</tr>
<tr>
<td>NO OF OBS.</td>
<td>149</td>
<td>170</td>
</tr>
<tr>
<td>% EXCEEDING SPEED LIMIT</td>
<td>65.8</td>
<td>92.4</td>
</tr>
</tbody>
</table>
### TABLE 3

**NET SPEED REDUCTIONS (MPH) FOR 1 RADAR TREATMENT AT SITE 2**

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Between Station 1 and Station 2</th>
<th>Between Station 1 and Station 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Net Speed Reduction</td>
<td>t-Test Inference</td>
</tr>
<tr>
<td>Cars</td>
<td>-1.1</td>
<td>not sig.</td>
</tr>
<tr>
<td>Trucks</td>
<td>0.5</td>
<td>not sig.</td>
</tr>
</tbody>
</table>

*Net Speed Reduction for Cars*

The net speed reduction for cars at Station 2 was -1.1 mph which may be considered a speed increase. The result of a t-test indicated that the net speed change was not significant. This means that activating one radar did not additionally reduce the average speed of cars. The net speed reduction for cars at Station 3 was -0.5 mph which was also considered not statistically significant. These values have demonstrated that using 1 radar was not effective in reducing the speed of cars at this location.

*Net Speed Reduction for Trucks*

The net speed reductions for trucks at Stations 2 and 3 were not statistically significant, as represented by 0.5 and -0.7 mph. Thus, the radar was not effective in lowering the speed of trucks at this location. The lack of effectiveness may be explained by the fact that in less than half an hour the drivers with CBs found out that it was drone radar and that there was no police car in the work zone.

**Conclusions 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 1 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.
Description of 2 Radar Experiment at Site 2

In Experiment 3, two radar guns were activated in the work zone. One radar was located near Station 2 and the second radar was near Station 3. Some drivers suspected that in some work zones drone radar is activated. Thus, they may not consider the drone radar as an indication of a serious threat of police presence. Therefore, two radar guns were used to increase the perceived "threat" of police presence in the work zone, and to make it difficult for drivers to find out where the radar was located and who was transmitting the radar signals. 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 keep lower speeds.

Similar to Experiment 2, vehicle speeds were measured at 3 speed stations, and two CB radios were used to monitor the conversation among drivers. Station 2 and 3 were also monitored to record any unusual behavior that might disturb the normal flow of traffic near the stations. The flashing lights on the speed limit signs were on during data collection. Police were not present in the work zone, and the construction crew was working on the bridge over Route 16.

The radar near Station 2 was in a car parked on the northbound direction and was aimed at the drivers in the southbound direction. A research assistant stayed inside a small passenger car and monitored the traffic around Station 2. The second radar was placed in a tree that was located near Station 3 and aimed at the southbound traffic. A tree was selected which was close to an overpass in order to give the impression that police might be at the overpass. Another research assistant stayed in a car parked on the northbound shoulder and monitored the traffic and CB conversation around Station 3.

Highlights from CB Monitoring

The study team used K and X-band radar guns and activated them at 1:40 pm. The K band radar gun was placed in a car parked in the northbound direction and the X band radar was in the tree. Both were facing the traffic in the southbound lanes. From the beginning of this experiment an extensive conversation was going on among drivers to find out whether or not it was a false radar signal and they tried to find out where it was located. It should be noted that the study team was able to hear only parts of their conversation when the drivers were close to the team. To show the extent of the communication among drivers, an example of actual conversations heard on the CB radio near Station 2, during a 45-minute time period, is listed below:

2:17 pm "Smokey bear doing a loop over here at 189, sitting there in northbound"
A similar conversation went on indicating that drivers were still trying to find out where the radar guns were located and whether the threat was real. From the CB monitoring it became clear that drivers could not conclude whether it was false radar and where it was located and how many were being used. It was clear that the drivers were alerted to the situation and radar transmission attracted their attention.

Data Analysis for 2 Radar Experiment at Site 2

Data for 2 Radar treatment were collected for about 3 hours (2 hours and 45 minutes). The data for 2 Radar treatment were divided into three one-hour (55 minutes) time periods. These time periods are referred to here as Interval I, Interval II, and Interval III, designating the first, second, and third hours,
respectively. This method was used to examine the lasting effects of drone radar. This section provides a brief description of speed characteristics and discusses the net effects of using two radar guns in the work zone. A more detailed discussion of speed distributions and percent of vehicles exceeding a speed level is given in Appendix C. The control data for this experiment was the same as that of 1 Radar treatment at Site 2.

The construction crew was working on the bridge over Route 16 until 3:30 pm. After 3:30 pm all workers left the Route 16 bridge. It should be remembered that 3:30 pm is the beginning our Interval III. There were 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 Speed Characteristics

A summary of speed statistics for each time interval in each station is given in Tables 4, 5, and 6. It is reminded that the control data for 2 Radar treatment is the same data used for 1 Radar Experiment at Site 2; thus, it is not discussed here. For all three time intervals the average speeds were lower at Station 2 compared to Station 1, but higher at Station 3 compared to Station 2. This speed trend was similar for cars and trucks (see Figures 6 and 7).

At Station 1, the maximum speeds varied from 83 to 87 mph for cars and from 74 to 79 mph for trucks. The average speeds of cars and trucks were approximately 2-4 mph and 7-9 mph, respectively, higher than their speed limits at Station 1. At Station 2, cars and trucks demonstrated maximum speeds varying from 65 to 71 mph and 57 to 61 mph, respectively, with average speeds approximately 7-11 mph and 0-3 mph, respectively, faster than 45 mph. At Station 3, cars and trucks had average speeds of 12-15 mph and 8-9 mph, respectively, higher than the speed limit of 45 mph. At Station 3, the maximum speeds varied from 72 to 74 mph and 63 to 65 mph for cars and trucks, respectively (see Tables 4, 5, and 6).

Cars and trucks exceeded the speed limits both inside and outside of the work zone. Approximately 69-81% of cars and 90-95% of trucks traveled faster than their respective speed limits at Station 1 (Table 4). At Station 2, 84-94% of cars and 37-75% of trucks were speeding (Table 5). At Station 3, 97-99% of car and 95-100% of truck drivers traveled faster than the speed limit of 45 mph (Table 6). Cars and trucks increased their speeds after passing the work zone as the average speed and the percent exceeding numbers indicated, (see Figures C.1 to C.6).
Figure 6. Average speeds for cars at Site 2 - 2 Radar Intervals I-III

Figure 7. Average speeds for trucks at Site 2 - 2 Radar Intervals I-III
### TABLE 4

SPEED STATISTICS FOR 2 RADAR TREATMENT AT SITE 2 - STATION 1

<table>
<thead>
<tr>
<th>VEHICLE TYPE</th>
<th>CARS</th>
<th></th>
<th>TRUCKS</th>
<th></th>
<th></th>
<th></th>
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<tr>
<td>INTERVAL</td>
<td>I</td>
<td>II</td>
<td>III</td>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>MEAN SPEED</td>
<td>67.7</td>
<td>68.4</td>
<td>69.2</td>
<td>61.5</td>
<td>63.7</td>
<td>62.8</td>
</tr>
<tr>
<td>MIN. SPEED</td>
<td>50</td>
<td>50</td>
<td>55</td>
<td>50</td>
<td>52</td>
<td>53</td>
</tr>
<tr>
<td>MAX. SPEED</td>
<td>87</td>
<td>84</td>
<td>83</td>
<td>74</td>
<td>75</td>
<td>79</td>
</tr>
<tr>
<td>STANDARD DEVIATION</td>
<td>5.28</td>
<td>5.46</td>
<td>4.82</td>
<td>4.87</td>
<td>4.37</td>
<td>5.26</td>
</tr>
<tr>
<td>NO OF OBS.</td>
<td>107</td>
<td>154</td>
<td>122</td>
<td>36</td>
<td>41</td>
<td>50</td>
</tr>
<tr>
<td>% EXCEEDING SPEED LIMIT</td>
<td>69.2</td>
<td>77.9</td>
<td>81.1</td>
<td>91.7</td>
<td>95.1</td>
<td>90.0</td>
</tr>
</tbody>
</table>

### TABLE 5

SPEED STATISTICS FOR 2 RADAR TREATMENT AT SITE 2 - STATION 2

<table>
<thead>
<tr>
<th>VEHICLE TYPE</th>
<th>CARS</th>
<th></th>
<th>TRUCKS</th>
<th></th>
<th></th>
<th></th>
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<td>INTERVAL</td>
<td>I</td>
<td>II</td>
<td>III</td>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>MEAN SPEED</td>
<td>51.7</td>
<td>53.6</td>
<td>56.1</td>
<td>44.9</td>
<td>47.3</td>
<td>48.1</td>
</tr>
<tr>
<td>MIN. SPEED</td>
<td>41</td>
<td>34</td>
<td>43</td>
<td>35</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>MAX. SPEED</td>
<td>65</td>
<td>71</td>
<td>70</td>
<td>57</td>
<td>61</td>
<td>59</td>
</tr>
<tr>
<td>STANDARD DEVIATION</td>
<td>5.97</td>
<td>7.60</td>
<td>6.07</td>
<td>4.12</td>
<td>6.17</td>
<td>4.11</td>
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<td>NO OF OBS.</td>
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<td>115</td>
<td>104</td>
<td>43</td>
<td>44</td>
<td>57</td>
</tr>
<tr>
<td>% EXCEEDING SPEED LIMIT</td>
<td>83.9</td>
<td>88.7</td>
<td>94.2</td>
<td>37.2</td>
<td>56.8</td>
<td>75.4</td>
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</table>

### TABLE 6

SPEED STATISTICS FOR 2 RADAR TREATMENT AT SITE 2 - STATION 3

<table>
<thead>
<tr>
<th>VEHICLE TYPE</th>
<th>CARS</th>
<th></th>
<th>TRUCKS</th>
<th></th>
<th></th>
<th></th>
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</thead>
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<tr>
<td>INTERVAL</td>
<td>I</td>
<td>II</td>
<td>III</td>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>MEAN SPEED</td>
<td>57.3</td>
<td>58.1</td>
<td>60.5</td>
<td>53.3</td>
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<td>MAX. SPEED</td>
<td>72</td>
<td>73</td>
<td>74</td>
<td>63</td>
<td>65</td>
<td>63</td>
</tr>
<tr>
<td>STANDARD DEVIATION</td>
<td>6.15</td>
<td>7.20</td>
<td>6.33</td>
<td>4.90</td>
<td>5.01</td>
<td>4.46</td>
</tr>
<tr>
<td>NO OF OBS.</td>
<td>92</td>
<td>94</td>
<td>91</td>
<td>38</td>
<td>36</td>
<td>46</td>
</tr>
<tr>
<td>% EXCEEDING SPEED LIMIT</td>
<td>97.8</td>
<td>96.8</td>
<td>98.9</td>
<td>94.7</td>
<td>100.0</td>
<td>97.8</td>
</tr>
</tbody>
</table>
Net Speed Reductions

For all three time intervals, the net speed reductions for cars and trucks were computed using the procedure described in the Study Approach section. The net reductions are summarized in Table 7 and discussed in the following sections.

TABLE 7

NET SPEED REDUCTION (MPH) FOR 2 RADAR TREATMENT AT SITE 2

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Between Station 1 and Station 2</th>
<th>Between Station 1 and Station 3</th>
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<tr>
<td></td>
<td>Net Speed Reduction</td>
<td>t-Test Inference</td>
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<tr>
<td>--------------</td>
<td>---------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td><strong>INTERVAL I</strong></td>
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<td></td>
</tr>
<tr>
<td>Cars</td>
<td>1.2</td>
<td>not sig.</td>
</tr>
<tr>
<td>Trucks</td>
<td>3.2</td>
<td>significant</td>
</tr>
<tr>
<td><strong>INTERVAL II</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cars</td>
<td>0.0</td>
<td>not sig.</td>
</tr>
<tr>
<td>Trucks</td>
<td>3.1</td>
<td>significant</td>
</tr>
<tr>
<td><strong>INTERVAL III</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cars</td>
<td>-1.7</td>
<td>significant</td>
</tr>
<tr>
<td>Trucks</td>
<td>1.2</td>
<td>not sig.</td>
</tr>
</tbody>
</table>

Net Speed Reduction for Cars

For cars at Station 2, there was a 1.22 mph net reduction during the first hour (in Interval I), no additional speed reduction in the second hour (Interval II), and 1.69 mph of net
increase during the third hour (Interval III). The reductions for Interval I and II were not statistically significant. However, the net increase in the third hour was significant. This increase cannot be attributed to activating radar, because any effect would be pointed out by a decrease (positive net speed) and not an increase (negative net speed).

For cars at Station 3, the 2 Radar treatment caused net speed reductions of 2.87, 2.74, and 1.17 mph for Intervals I, II, and III, respectively. It should be noted that the amount of net reductions at Stations 2 and 3 decreased from time Interval I to time Interval III. The reductions for Intervals I and II are statistically significant, but for Interval III it was not.

One reason for the speed increase in Interval III might be due to absence of crew over the route 16 bridge during Interval III. It should be noted that, the workers left the work site over bridge at the beginning of Interval III, but the speed limit remained 45 mph till the end of Interval III. The route 16 bridge was approximately 1,000 ft from our speed Station 2. Drivers may have increased their speeds after noticing that there were no workers on the bridge.

Net Speed Reduction for Trucks

For trucks at Station 2, there was a net speed reduction of 3.24 mph in the first hour, 3.05 mph in the second hour, and 1.24 mph during the third hour of activating two radar guns. The reductions in time Intervals I and II were statistically significant, but the reduction in Interval III was not significant. The numbers indicate that trucks reduced their speeds at Station 2 when the radar was activated.

For trucks at Station 3, net speed reductions of 2.90, 5.80, and 3.88 mph were achieved during Intervals I, II, and III, respectively. These reductions are statistically significant, indicating that activating two radar guns caused additional speed reductions of 3-6 mph in trucks. It should be noted that Station 3 was located after the work space where drivers tended to increase their speeds. Besides this, during Interval III truck drivers may have increased their speeds at Station 3 because they did not any crew working on the bridge. The net speed reduction decreased over time at Station 2, but fluctuated at Station 3. The reason may be due to the fact that at Station 3 the radar was placed in a tree and truck drivers could not locate where the radar signals were coming from, as CB monitoring indicated.

Conclusions From 2 Radar Experiment at Site 2

The results indicated that, in general, there were additional speed reductions due to activating 2 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 less effectiveness on cars might be that cars do not utilize CB radios as much as truck drivers do. Thus, car drivers may not have been aware of the radar transmission.

Another 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 working over the route 16 bridge during Interval III. Drivers may have increased their speeds after noticing that there were no working action going on the bridge.

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.
SUMMARY AND CONCLUSIONS

The results from Experiments 1-3 indicated that the use of drone radar in most cases additionally reduced the average speed of vehicles in the work zones. The additional speed reductions are summarized in Figure 8 for cars and Figure 9 for trucks. Each experiment presented conditions that have to be considered in evaluating the effectiveness of the drone radar.

1 Radar Treatment at Site 1 (Experiment 1)

Net speed reductions of 8.0 mph for cars and 9.8 mph for trucks were obtained when one drone radar was used for a short period of time (less than an hour) in a work zone where vehicles were going very fast both inside and outside of the work zone. The percentage of fast moving vehicles significantly decreased at Station 2 when the radar was activated. These reductions were for short time periods, in particular, the value for trucks was computed from a small sample of observations; thus, it may not represent typical speed reduction effects that drone radar might have on vehicles. From 1 Radar Experiment at Site 1, it was concluded that for a short time period 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 task in which the crew spent less than an hour in one location.

1 Radar Treatment at Site 2 (Experiment 2)

The results from this experiment indicated that using drone radar at this site did not lead to additional speed reductions on the average speed of cars and trucks. Furthermore, the decreases in the percentages of vehicles with excessive speeds during the treatment compared to the control data were relatively small. The effectiveness of one drone radar at Site 2 was not as significant as it was at Site 1. One reason for this difference may rely on the fact that cars and trucks at Site 2 were traveling at much lower speeds than those at Site 1. At Station 2, for example, the average speed of cars was several mph higher than the speed limit while the average speed of trucks was slightly over the speed limit. Another reason may be due to the duration of the radar transmission. The time period for Site 2 was about three times longer than that of Site 1, and the drivers had enough time to figure out where the radar was and who was activating it. In fact, within 27 minutes some of the drivers were aware that there were no police present in the work zone, and they were not really threatened by the radar signal transmission.
Figure 8. Net speed reductions for cars - Experiments 1, 2, and 3

* means not significant

Figure 9. Net speed reductions for trucks - Experiments 1, 2, and 3

* means not significant
2 Radar Treatment at Site 2 (Experiment 3)

The results from Experiment 3 indicated that there were additional speed reductions when drivers could not figure out whether or not it was drone radar. The additional speed reductions were consistent in trucks, but not in cars. In five out of six cases, trucks showed statistically significant net speed reductions. Cars showed statistically significant net reductions only in two out of six cases. Trucks invariably showed a net speed reduction when radar guns were activated. Trucks additionally reduced their speeds by 1.2 to 3.2 mph at Station 2, and by 2.9 to 5.8 mph at Station 3 when two radar guns were used. The speed reduction effects of drone radar did not diminish on trucks over a time period of approximately three hours.

Cars did not show statistically significant net speed reductions at Station 2. However, at Station 3 cars presented net speed reductions from 1.2 to 2.9 mph. Therefore, transmitting radar signals inside the work zone may or may not affect the average speeds of passenger cars, depending upon the location of the station of measurement.

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.

The differences in the percentage of vehicles exceeding the speed limits during Two-Radar treatment and the Control period presented distinct trends for each station. At Station 1 and 3, there were no significant reductions due to the use of radar. However, at Station 2, cars and trucks had speed reductions which decreased over time. The reductions for cars were 12, 7, and 2 percent, and 38, 18, and 0 percent for trucks in Interval I, II, and III, respectively.

Drivers with a radar detector and/or a CB talked about possible police presence in the work zone. The level of communication indicated that they paid more attention to their speeds in the work zone when threat of police presence existed. Paying more attention to traveling in work zones would in turn increase traffic safety in work zones. Thus, another benefit of radar use was an increase in drivers concern about their speeds which led to an increase in their awareness/attention to traveling through work zones. The results indicated that the effects of drone radar on trucks did not diminish over time. Drivers with CB radios were still concerned about a possible presence of police in the work zone.
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 a longer period 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.

REFERENCES


Description of Site for Experiment 1

The study site was located in the northbound direction of I-57 just south of Champaign, Illinois. The highway was a four-lane highway, with two lanes in each direction. The terrain in this area was level, and the roadway did not have noticeably sharp curves. The Average Daily Traffic (ADT) on this section of the freeway was around 14,500 with approximately 17% large trucks. 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. The signs were located at the end of the lane closure taper. The traffic control plans are shown in Figure A.1.

The construction zone was approximately 5 miles long in the northbound direction. One of the two lanes in each direction of travel was closed to allow for activities such as patching, joint repair, or resurfacing. The construction crew for these activities consisted of approximately four to five workmen and a flagger. The crew used light mobile construction equipment (a pick-up truck, a small roller, jack hammer, small asphalt truck, etc.) to permit movements from one location to another. The crew was working far from Station 2; thus, the speed measurements were not influenced by their presence. The closed lane was delineated by orange barrels.

Speed Characteristics

A summary of speed characteristics for Experiment 1 is presented in Tables A.1 and A.2. At Station 1, during the control period, trucks and cars were traveling 9.9 and 10.1 mph over their respective speed limits. At Station 2, the average speeds of cars and trucks were 18.8 and 13.5 mph over the speed limit, respectively, for the control period. When the radar was activated, at Station 1, cars traveled 8.8 mph and trucks 9.5 mph over their respective speed limits. However, at Station 2 cars traveled 9.3 mph and trucks 3.3 mph faster than the speed limit.

In the control period, the percentages of cars exceeding the speed limits were 93% and 100% at Stations 1 and 2, respectively. Similarly, 97% of trucks at Station 1 and 100% at Station 2 had speeds higher than the speed limits (Table A.1). Nearly 50% of cars and 42% of trucks exceeded their respective speed limits by more than 10 mph at Station 1. Likewise, at Station 2 about 86% of cars and 69% of trucks traveled at 55 mph or faster in the work zone with a 45 mph speed limit (Figures A.2 and A.4).

In the 1 radar treatment period, approximately 91% of cars and 100% of trucks at Station 1, and 91% of cars and 77% of trucks at
Station 2 exceeded their speed limits (Table A.2). At Station 1, about 38% of cars and 33% of trucks had driven at least 10 mph faster than their respective speed limits. At Station 2, nearly 40% of cars and 15% of trucks traveled faster than 55 mph (Figures A.3 and A.5).
### TABLE A.1

**SPEED STATISTICS FOR CONTROL DATA AT SITE 1**

<table>
<thead>
<tr>
<th>VEHICLE TYPE</th>
<th>CARS</th>
<th>TRUCKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATION</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>MEAN SPEED</td>
<td>75.1</td>
<td>63.8</td>
</tr>
<tr>
<td>MIN. SPEED</td>
<td>55</td>
<td>47</td>
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<tr>
<td>MAX. SPEED</td>
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<td>87</td>
</tr>
<tr>
<td>STANDARD DEVIATION</td>
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<td>7.71</td>
</tr>
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<td>NO OF OBS.</td>
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<td>178</td>
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<td>% EXCEEDING SPEED LIMIT</td>
<td>92.5</td>
<td>100</td>
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<td>MIN. SPEED</td>
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<td>48</td>
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<tr>
<td>MAX. SPEED</td>
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<tr>
<td>STANDARD DEVIATION</td>
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<td>5.36</td>
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<tr>
<td>NO OF OBS.</td>
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<td>26</td>
</tr>
<tr>
<td>% EXCEEDING SPEED LIMIT</td>
<td>97.2</td>
<td>100</td>
</tr>
</tbody>
</table>

### TABLE A.2

**SPEED STATISTICS FOR 1 RADAR TREATMENT AT SITE 1**

<table>
<thead>
<tr>
<th>VEHICLE TYPE</th>
<th>CARS</th>
<th>TRUCKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATION</td>
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<td>2</td>
</tr>
<tr>
<td>MEAN SPEED</td>
<td>73.8</td>
<td>54.3</td>
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<tr>
<td>MIN. SPEED</td>
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<td>STANDARD DEVIATION</td>
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<td>% EXCEEDING SPEED LIMIT</td>
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<td>2</td>
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<td>64.5</td>
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<td>MIN. SPEED</td>
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<td>MAX. SPEED</td>
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<td>STANDARD DEVIATION</td>
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<td>NO OF OBS.</td>
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<tr>
<td>% EXCEEDING SPEED LIMIT</td>
<td>100</td>
<td>76.9</td>
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Net Speed Reductions

The net speed reductions at Station 2 are summarized in Table A.3. The data analysis approach is discussed in the Study Approach section. This drone radar experiment resulted in net speed reductions of 8.0 mph on cars and 9.8 mph on trucks. Obviously, these reductions were statistically and practically significant. However, it is important to remember that the sample size for trucks was small and the duration of radar transmission was short.

<table>
<thead>
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<th>Vehicle Type</th>
<th>Net Speed Reduction</th>
<th>t-Test Inference</th>
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<tbody>
<tr>
<td>Cars</td>
<td>8.0</td>
<td>significant</td>
</tr>
<tr>
<td>Trucks</td>
<td>9.8</td>
<td>significant</td>
</tr>
</tbody>
</table>

**TABLE A.3**

NET SPEED REDUCTIONS (MPH) FOR 1 RADAR TREATMENT AT SITE 1

Conclusions from 1 Radar Experiment at Site 1

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 outside of the work zone. As a result, the speeding drivers may have been more concerned about police threat than if they were traveling at speeds closer to 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 short time period. When drivers find out that drone radar is used, and there are no police in the work zone, they might not feel the need to slow down 8-10 mph.
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. Also, drivers with a radar detector may increase their speeds after passing the radar location.
4) The net reduction for trucks is computed based on a small sample of truck 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 very short-term use the drone radar was effective in reducing the 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 simulates a short-term maintenance job where the crew spent less than an hour in one location. Because of the limitations of Experiment 1, more experiments were conducted to address some of the aforementioned shortcomings.
Figure A.1. Work zone signs on NB I-57 (Site 1) during drone radar study

PLASTIC BARRELS

END CONSTRUCTION

FLAGMAN AHEAD

WORKERS AHEAD

SPEED LIMIT 45
WHEN FLASHING

45 M.P.H.
LEFT LANE CLOSED AHEAD

LEFT LANE CLOSED 1/2 MILE

ROAD CONSTRUCTION 1 MILE

Give' em a BRAKE Slow Down

Indicates arrow board

Not to scale
Figure A.2. Cars speed frequency in Control data for Site 1

Figure A.3. Trucks speed frequency in Control data for Site 1
Figure A.4. Cars speed frequency in 1 Radar data for Site 1

Figure A.5. Trucks speed frequency in 1 Radar data for Site 1
In the following sections the speed characteristics for cars and trucks in the control and 1 Radar treatment in Experiment 2 are discussed. A summary of speed statistics is given in Tables 1 and 2. The percentages of vehicles exceeding a given speed at Stations 1, 2, and 3 are presented in Figures B.1 through B.4. Also, speed frequency distributions at Station 1, 2 and 3 are shown in Figures B.5 and B.6 for control data, and in Figures B.7 and B.8 for the treatment data.

Control Data for Experiment 2

Speed Characteristics of Cars

Cars reduced their speeds at Station 2 compared to Station 1, but increased to higher speeds by the time they reached Station 3. This speed trend can be clearly observed by the average speeds for passenger cars in Figure 4. The average speeds of cars were 3.3 to 15.7 mph higher than the speed limits (Table 1). Station 3 presented the highest (15.7 mph) difference between the average speed and speed limit. The speed distribution at Station 1 had the widest range (36 mph). However, the highest standard deviation of 6.35 mph was presented at Station 3.

Approximately 73.4% of cars were traveling at speeds higher than the 65 mph speed limit at Station 1. At Station 2 and Station 3, the percentage of cars exceeding the 45 mph speed limit were even higher than that of Station 1, as represented by 95.9% and 98.9%, respectively. The percentages of cars exceeding a given speed level are given in Figure B.1. Approximately 6.2%, 34.2%, and 79.7% of cars at Stations 1, 2, and 3, respectively, exceeded the speed limit by more than 10 mph.

Speed Characteristics of Trucks

Trucks also reduced their speeds at Station 2 compared to Station 1, but increased them by the time they reached Station 3. This speed change can be observed by the average speeds for trucks in Figure 5. The average speeds of trucks were 4.2 to 12.3 mph higher than the speed limit throughout Stations 1, 2, and 3 (Table 1). Similar to passenger cars, Station 3 presented the highest difference for average speed and speed limit, as represented by approximately 12.3 mph. The speed distributions at Station 1 and Station 3 had the widest range (37 mph), with the highest standard deviation of 6.03 being presented at Station 3.

Approximately 89.3% of trucks were driven at speeds higher than the 55 mph speed limit at Station 1. At Station 2 and
Station 3, the percentages of trucks traveling above the 45 mph speed limit were 75.4% and 96.9%, respectively. The percentages of trucks speeding 10 mph above the speed limit were approximately 27.7%, 9.6%, and 68.0% at Stations 1, 2, and 3, respectively. The percentages of trucks exceeding a given speed level are shown in Figure B.2.

1 Radar Treatment at Site 2

Speed Characteristics of Cars

On the average, cars traveled from 2.1 to 15.2 mph faster than the speed limit (Table 2). Station 3 presented the highest difference between the average speed and the posted speed limit, as represented by approximately 15.2 mph. However, the widest speed range of 41 mph and the highest standard deviation of 6.03 mph were displayed at Station 1. The percentages of cars exceeding a given speed are displayed in Figure B.3. The percentages of cars exceeding the speed limit were 65.8%, 92.4%, and 98.9% at Stations 1, 2 and 3, respectively. Nearly 4.7% of cars were traveling higher than 75 mph at Station 1. Approximately 37.6% and 82.8% of cars had speeds higher than 55 mph at Stations 2 and 3, respectively. The percentage of cars exceeding the speed limit by more than 10 mph was higher at Station 3 than at Station 1, despite the fact that Station 3 was inside the work zone.

Speed Characteristics of Trucks

Trucks had the highest standard deviation at Stations 1 and 3. The difference between the average speeds and the posted speed limits for trucks varied from 3.0 to 12.3 mph. Trucks displayed a more dispersed speed frequency throughout the three stations compared to the control data (Figures B.6 and B.8). The percentages of trucks exceeding speed limit were about 87.5%, 70.4% and 98.2%, at Stations 1, 2, and 3, respectively. The percentage of trucks with 65 mph speed or higher was about 21.6% at Station 1. At Stations 2 and 3, the percentages of trucks traveling faster than 55 mph were 4.1% and 60%, respectively (Figures B.3 and B.4).
Figure B.1. PERCENT OF CARS EXCEEDING A GIVEN SPEED AT SITE 2 - CONTROL DATA

Figure B.2. PERCENT OF TRUCKS EXCEEDING A GIVEN SPEED AT SITE 2 - CONTROL DATA
Figure B.3. PERCENT OF CARS EXCEEDING A GIVEN SPEED AT SITE 2 - 1 RADAR

Figure B.4. PERCENT OF TRUCKS EXCEEDING A GIVEN SPEED AT SITE 2 - 1 RADAR
Figure B.5. Cars speed frequency in Control data for Site 2

Figure B.6. Trucks speed frequency in Control data for Site 2
Figure B.7. Cars speed frequency in Radar data for Site 2.

Figure B.8. Trucks speed frequency in Radar for Site 2.
APPENDIX C - SPEED CHARACTERISTICS FOR 2 RADAR AT SITE 2

As mentioned earlier in the description of data collection procedures, the data for the 2 Radar Experiment at Site 2 were gathered based upon three intervals of one hour each. Statistical analysis has been conducted for each interval separately and a summary of the speed statistics is given in Tables 4, 5, and 6. The percentages of vehicles exceeding a given speed at Stations 1, 2, and 3 in each interval are displayed in Figures C.1 through C.6. Also, the speed distributions for each interval in all three stations are shown in Figures C.7 through C.12. Furthermore, Figures C.13 through C.18 show the speed frequency variations for each station in all three intervals.

Speed Characteristics of Cars

For all three intervals, cars reduced their speeds at Station 2 compared to Station 1, returning to higher speeds (although below those presented at Station 1) when crossing Station 3 (Figures C.7, C.9, and C.11). Despite the limited use of CBs among passenger car drivers, data have shown that car speeds slightly increased from Interval I to Interval III.

Interval I

In Interval I, according to Tables 4, 5, and 6, the average speeds of cars were 2.7 to 12.3 mph higher than the posted speed limits. The highest difference for average speed and speed limit was observed at Station 3, being approximately 12.3 mph. Also, the highest standard deviation was depicted at Station 3, despite the widest range being presented at Station 1, which was approximately 37 mph (Tables 4 and 6). According to Tables 4, 5, and 6, the percentages of cars traveling faster than the speed limit were approximately 69.2%, 83.9%, and 97.8% at Stations 1, 2, and 3, respectively. The high percentages of cars traveling higher than the speed limit through work zone demonstrates that the lowering of speed within construction zones is a real challenge for traffic engineers (Figure C.1).

According to Figure C.7, the percentages of cars traveling faster than 10 mph over the speed limit during Interval I were nearly 5.6%, 27.4%, and 58.7% at Stations 1, 2, and 3, respectively. At Station 3, 7.6% of passenger cars drove faster than 65 mph in a zone that had a speed limit of 45 mph.

Interval II

In Interval II, cars presented higher speed figures than
those shown in Interval I. According to Tables 4, 5, and 6, the average speeds of cars in Interval II were 3.4 to 13.1 mph higher than the posted speed limits. Similarly to Interval I, the highest difference for average speed and speed limit was displayed at Station 3. However, the highest standard deviation and the widest range (37 mph) was presented at Station 2 (Table 5). According to Figure C.3, the percentages of cars traveling faster than the speed limit were approximately 77.9%, 88.7%, and 96.8% at Stations 1, 2, and 3, respectively. The percentages of cars traveling faster than 10 mph above the speed limit were approximately 5.2%, 40.0%, and 59.6% at Stations 1, 2, and 3, respectively. These percentages are even higher than those presented for Interval I, mainly the one displayed at Station 2. Moreover, at Station 3, similarly to Interval I, approximately 13.8% of passenger cars continued to travel at speeds higher than 65 mph (Figure C.9).

Interval III

In Interval III, as it was mentioned above, the ascending speed trend of passenger cars throughout the three intervals reached its upper limit. According to Tables 4, 5, and 6, the average speeds of cars in Interval III varied from 4.2 to 15.5 above the posted speed limits. The highest difference of 15.5 mph between the average speed and the speed limit was presented at Station 3, followed by the highest standard deviation and the widest range (30 mph) at that very same station.

The percentages of cars traveling faster than the posted speed limit were 81.1%, 94.2%, and 98.9% at Stations 1, 2, and 3, respectively (Figure C.5). These percentages have been the highest ones among the three intervals. According to Figure C.11, the percentages of cars traveling faster than 10 mph above the speed limit were approximately 10.7%, 54.8%, and 75.8% at Stations 1, 2, and 3. Following the same trend as Intervals I and II, at Station 3 approximately 22.0% of passenger cars traveled at speeds higher than 65 mph, which may be considered excessively high for construction zones (Figure C.17).

Speed Characteristics of Trucks

Trucks did not show remarkable differences in average speeds for the same station within each interval (Figure 7). Nonetheless, trucks had reduced their speeds at Station 2 compared to Station 1, with increases at Station 3 (Figures C.14, C.16, C.18).