Temporal Speed Reduction Effects of Drone Radar in Work Zones

RAHIM F. BENEKOHAL, PAULO T. V. RESENDE, AND WEIXIONG ZHAO

Three experiments were conducted to evaluate the effectiveness of using drone (passive or unmanned) radar guns on vehicle speeds in work zones. Experiment 1 was an exploratory study to determine the immediate effects of using one drone radar gun on speed. Experiment 2 was conducted to evaluate the short-term effects of using one drone radar gun on speed. Experiment 3 measured the short-term effects of using two drone radar guns on speed. It was divided into three 1-hr time intervals to determine the lasting effects of using two radar guns on speed. The immediate effect of using one radar gun (Experiment 1) was a speed reduction of 13 to 16 km/hr (8 to 10 mph); however, such reduction should not be taken as a typical value. Experiment 2 showed that using one radar gun was not effective in reducing speed when drivers knew that it was drone radar. Experiment 3 indicated that the use of two radar guns increased the radar effectiveness, since drivers were not sure whether the signals would come from a police radar or drone radar. The effectiveness was consistent on trucks, but not on cars. The two-radar experiment reduced speeds of trucks by 5 to 10 km/hr (3 to 6 mph) in most cases, but speeds of cars were reduced by 5 km/hr (3 mph) only in two out of six cases. The speed reduction effects of the two-radar experiment on trucks were sustained over a time period of 3 hr.

Having a police officer in every work zone is a costly speed enforcement option. However, providing an indication of "threat" of police presence, such as using drone radar, is relatively inexpensive and may work to alleviate some of the speeding problems in work zones. This study was conducted to determine the short-term effects of using drone radar, also called passive or unmanned radar, and the lasting effects of continuous radar signal transmission on the speed of vehicles in a rural Interstate highway work zone in Illinois. At the time of this study, cars and trucks were still allowed to use radar detectors in Illinois.

The study consisted of three experiments. Experiment 1 was an exploratory study to evaluate the immediate (less than 1 hr) 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 2 was conducted to evaluate short-term (a few hours) effects of using one drone radar gun on speeds of vehicles. Experiment 3 was an attempt to determine the short-term effectiveness of using two drone radar guns as well as the lasting effects of radar signal transmission on vehicular speeds. In Experiment 3, two radar guns were used to increase the perceived "threat" of police and to make it difficult for the drivers to figure out the source of transmission. 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.

Traffic data were collected when one or two drone radar guns were added to standard Illinois Department of Transportation traffic control plans. These plans were prepared according to the procedures discussed in the *Manual on Uniform Traffic Control Devices* (MUTCD) (*1*). Figure 1 shows the work zone signs used during the drone radar study. Illinois uses two arrow boards in such work zones.

The study sites were located on a rural section of I-57 in central Illinois. The highway has two lanes in each direction, with one lane per direction closed during the construction period. Average daily traffic was approximately 12,000 with nearly 22 percent heavy commercial vehicles. The speed limit outside the construction zone was 105 km/hr (65 mph) for cars and 89 km/hr (55 mph) for heavy trucks (over 4 tons); inside the zone it was 72 km/hr (45 mph) for all vehicles. The regulatory 72 km/hr (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 used by law enforcement officers to measure speeds of vehicles. Warren (*2*) synthesized the effects of law enforcement on regular highway sections (not in work zones) and reported that in most cases police enforcement decreased speed by less than 5 km/hr (3 mph), but reductions of up to 16 km/hr (10 mph) were also noted. Pigman et al. (*3*) used drone radar at two high-accident locations (not in work zones) on I-75 and reported that it was effective in reducing speeds of vehicles traveling at excessive speeds. They showed that speeds of vehicles with radar detectors decreased significantly compared with speeds of vehicles lacking radar detectors. Pigman et al. (*3*) also reported that 42 percent of trucks and 11 percent of cars had radar detectors.

There has been a very limited number of studies dealing directly with the effects of drone radar on vehicle speeds in work zones. Richards et al. (*4*) reported that, in a construction zone on an urban freeway with 64-km/hr (40-mph) regulatory speed limit, a stationary patrol car with radar on caused 5 km/hr (3 mph) more speed reduction than a stationary patrol car with radar off. Ullman (*5*) reported that radar transmission, without police presence in work zones, reduced the average speed by less than 2.7 km/hr (1.7 mph) in seven out of eight study sites. On the eighth site, a reduction of 7.2 km/hr (4.5 mph) was obtained, but this reduction was computed on the basis of a small sample of observations (less than 30 vehicles) and therefore may not be very reliable.

Department of Civil Engineering, University of Illinois At Urbana-Champaign, 205 N. Mathews Ave., Urbana, Ill. 61801.

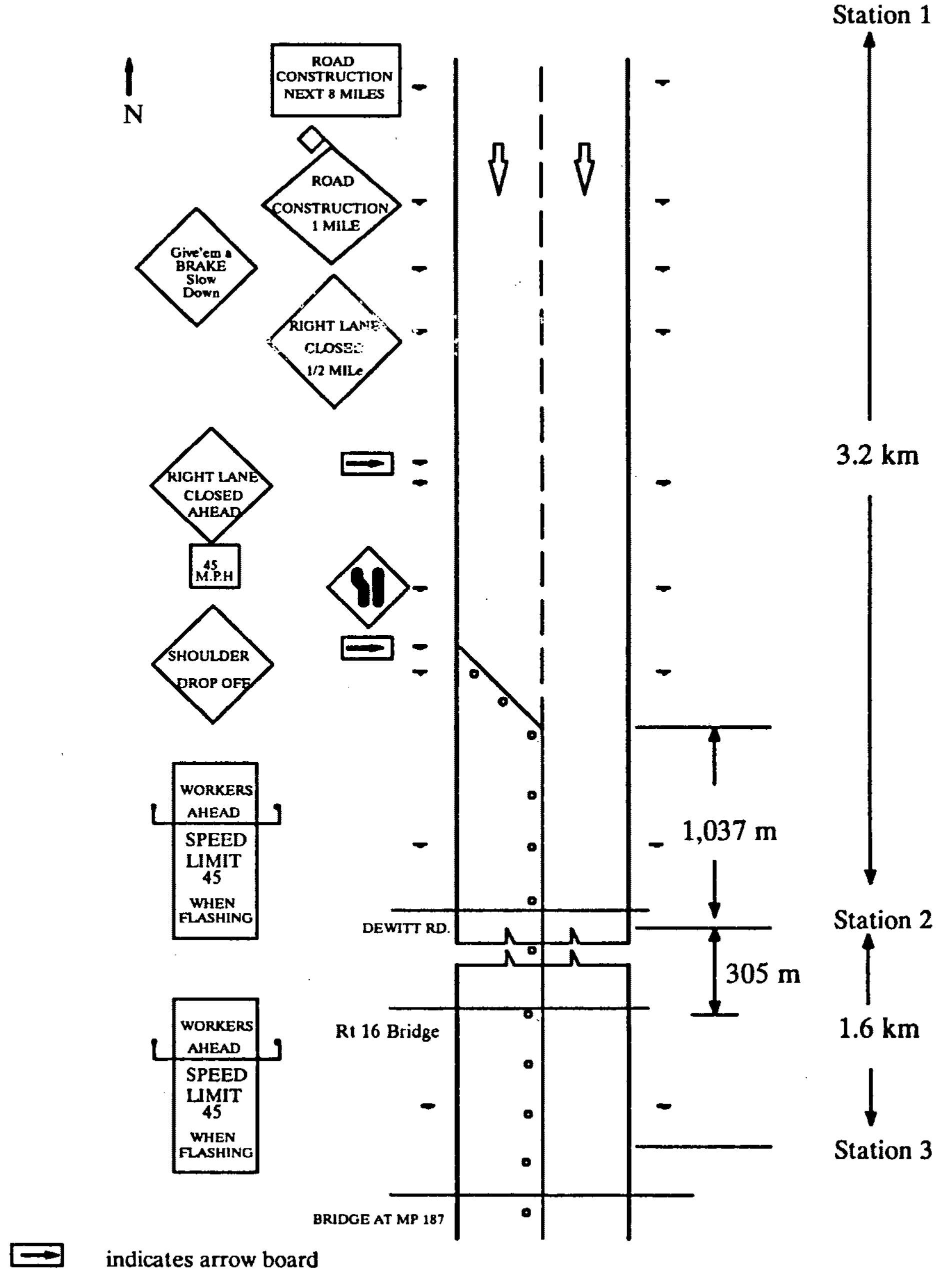

FIGURE 1 Work zone signs on southbound I-57 during drone radar study.

STUDY APPROACH

The approach used in this study is commonly known as before and after study with control group. Data collection and data analysis are performed according to this method.

Data Collection for Experiment 1

The study site was located in the northbound approach of a rural section of I-57 south of Champaign, Illinois (Site 1). Data were collected on September 22, 1989, for two time periods at two stations. During the first period (control) no drone radar was used. During the second period (one-radar treatment) one radar gun was used at Station 2. Control data were collected from 1:00 to 2:00 p.m. and treatment data from 2:15 to 2:50 p.m. Station 2 was located 260 m after the end of the lane closure taper where only one lane was open to traffic. Station 1 was located outside the work zone about 2.4 km before Station 2.

Data Collection for Experiments 2 and 3

Experiments 2 and 3 were carried out in a work zone on the southbound approach of a rural section of Interstate 57 near Mattoon, Illinois (Site 2). Data were collected at three locations. Station 1 was outside the work zone, and two others inside it (Figure 1). At Site 2, data were gathered for the following three conditions:

1. Control or base condition—no radar was used;
2. One-radar treatment (Experiment 2)—one radar gun was activated near Station 2; and
3. Two-radar treatment (Experiment 3)—two radar guns were activated simultaneously, one close to Station 2 and the other near Station 3.

Control data were collected from 10:00 a.m. to noon, June 12, 1990. For the one-radar treatment, they were gathered from 1:30 to 3:10 p.m., June 12, 1990. Data for the two-radar treatment were collected from 1:40 to 4:25 p.m., June 11, 1990. The two-radar treatment was divided into three 55-min periods to examine the lasting effects of drone radar. These time periods are denoted as Intervals I, II, and III, designating the first, second, and third periods, respectively.

Data Reduction

Vehicle speeds at each station were collected with mechanical traffic counters programmed to keep a record of individual vehicles. A Fortran program was written to perform sorting, classification, and error checking (*6*).

Data Analysis Approach

The minimum, mean, and maximum speeds, as well as standard deviation, frequency distribution, and percentage of vehicles exceeding a given speed level were determined. *F*-tests and *t*-tests were performed to compare speed variances and mean speeds, respectively. A 95 percent confidence level was used unless stated otherwise. Results of the *F*-test determined the type of *t*-test to be used for comparing the average speeds of the two data sets (*7*). Since free-flow speeds are used to compute speed variances, a change in variances should not be correlated with traffic safety in work zones.

An assumption in using the *t*-test is that the speed data ought to have a normal distribution. The data used in this study came from 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 (*8*). All statistical analyses were performed using PC-SAS (*7*). A separate statistical analysis was performed for cars and trucks because of the differences in posted speed limits as well as in speed distributions.

Net Speed Reduction Analysis

Net speed reductions were computed to determine whether there were additional speed reductions due to the use of drone radar in the work zone. The net speed changes were computed from the following:

$$\text{Net speed change at Station } n = (\overline{U}_{nt} - \overline{U}_{nc}) - (\overline{U}_{1t} - \overline{U}_{1c})$$

where

$\overline{U}_{1t}$ = the treatment mean speed at Station 1;
$\overline{U}_{nt}$ = the treatment mean speed at Station n, n = 2 or 3;
$\overline{U}_{1c}$ = the mean speed for control data at Station 1; and
$\overline{U}_{nc}$ = the mean speed for control data at Station n, n = 2 or 3.

A *t*-test with 95 percent confidence level was used to determine whether the net reduction was statistically significant.

ONE-RADAR EXPERIMENT AT SITE 1 (EXPERIMENT 1)

Description

At Site 1, one radar was activated near Station 2 for a short period. A citizens' band (CB) radio was used to monitor the conversation among drivers. During the data collection, the flashing lights on the speed limit signs were turned on to indicate that a regulatory 72-km/hr (45-mph) speed limit was in effect. The speed limit signs were located at the end of the lane closure taper. A small construction crew (four to five people) with light equipment and a pickup truck was working north of our 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. There were no police in the work zone.

Summary of Findings

The speed characteristics for the control and treatment data are given in Table 1. During the control period, cars and trucks at Station 1 were traveling at about 16 km/hr (10 mph) over their respective speed limits. At Station 2, the average speeds of cars and trucks were nearly 30.2 and 21.7 km/hr (18.8 and 13.5 mph), respectively, over the speed limit. During treatment, cars and trucks showed average speeds of approximately 118.8 and 103.8 km/hr (73.8 and 64.5 mph) at Station 1. At Station 2, average speeds were nearly 87.4 and 77.7 km/hr (54.3 and 48.3 mph). The drone radar experiment resulted in net speed reductions of more than 12.88 km/hr (8.00 mph) on cars and trucks. These reductions were found to be statistically significant.

The percentages of vehicles exceeding the speed limits at Station 1 were practically the same for treatment and control data. However, at Station 2, during the treatment period, there was a considerable decrease in these percentages for both cars and trucks.

Although this drone radar experiment resulted in net speed reductions of such magnitudes, these results are not typical and they have to be interpreted in the light of the following factors:

1. The net speed reductions were high because vehicles were traveling faster outside and inside the work zone. As a result, the speeding drivers may have been more concerned

TABLE 1 Speed Statistics at Site 1 (km/hr)

	CARS				TRUCKS			
STATION	1		2		1		2	
CONDITION*	Cont	Treat	Cont	Treat	Cont	Treat	Cont	Treat
MEAN SPEED	120.9	118.8	102.7	87.4	104.4	103.8	94.1	77.7
MIN. SPEED	88.5	88.5	75.6	67.6	85.3	94.9	77.2	57.9
MAX. SPEED	146.5	144.9	140.0	138.4	122.3	114.3	112.7	94.9
STANDARD DEVIATION	17.08	15.99	19.98	19.90	12.49	9.82	13.89	16.30
NO OF OBS.	173	116	178	96	36	21	26	13
% EXCEEDING SPEED LIMIT	92.5	91.4	100	90.6	97.2	100	100	76.9

* Cont = Control, Treat = Treatment

about the 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 were based on data collected in a very short time period.
3. The location of Station 2 was 259.2 m (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 was computed on the basis of a small sample of truck drivers who traveled in the work zone during the short time that the radar was activated. The long-term reductions were less likely to be so high.

From Experiment 1 at Site 1 it was concluded that, in a very short period of time, the drone radar was effective in reducing speeds 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 work where the crew spent less than 1 hr in one location. Because of the limitations of Experiment 1, two other experiments were conducted.

ANALYSIS OF ONE-RADAR EXPERIMENT AT SITE 2 (EXPERIMENT 2)

Description

The first experiment at Site 2 was conducted when one radar gun was activated near Station 2. Speeds of vehicles were measured at three stations, and two CB radios were used to monitor drivers' conversations. Stations 2 and 3 were also monitored to record any unusual behavior that might disturb the normal flow of traffic close to the stations. The flashing lights on the speed limit signs were on during data collection and no police were present in the work zone. The construction crew was working on the bridge over Route 16.

Speed Characteristics

The average speeds were lower at Station 2 than at Station 1 but higher at Station 3 than at Station 2 (Table 2). This speed trend was observed for both cars and trucks. The control data showed that car drivers traveled as high as 135.2 km/hr (84.0 mph) outside and 123.9 km/hr (77.0 mph) inside the work zone. Their average speeds exceeded the speed limit by approximately 5.2, 14.1, and 25.7 km/hr (3.2, 8.7, and 15.9 mph) at Stations 1, 2, and 3, respectively. The percentages of cars exceeding the speed limits were about 73, 96, and 99 percent at Stations 1, 2, and 3, respectively (Figure 2). The percentages exceeding a given speed were higher at Station 3 than at Station 2 and close to the percentages for Station 1, although Station 3 was still inside the work zone.

Truck drivers traveled as high as 132.0 km/hr (82.0 mph) outside and 115.9 km/hr (72.0 mph) inside the work zone during the control period. The average speeds were nearly 11.7, 7.2, and 20.5 km/hr (7.3, 4.5, and 12.7 mph) higher than speed limits at Stations 1, 2, and 3, respectively. The percentages exceeding speed limits at Stations 1, 2, and 3 were about 89, 75, and 97 percent, respectively (Figure 2). Like cars, trucks traveled at higher speeds at Station 3 than at Station 2. The percentages of trucks exceeding a given speed at Station 3 were comparable with those for Station 1 (Figure 3).

Data for the one-radar experiment indicated that the average speeds of cars were nearly 3.3, 14.1, and 24.9 km/hr (2.0, 8.7, and 15.5 mph) over the speed limits. Speeding cars made up approximately 66, 92, and 99 percent of free-flow car traffic at Stations 1, 2, and 3, respectively (Figure 3). In the one-radar experiment, the trends for percentages of cars exceeding given speed levels were similar to those of the control data (Figure 2).

During the one-radar treatment, trucks were traveling 10.6, 5.2, and 20.2 km/hr (6.6, 3.2, and 12.5 mph) faster than the speed limits. About 88, 70, and 98 percent were speeding at Station 1, 2, and 3, respectively (Figure 2). The distribution of trucks with excessive speeds showed that speeds at Station 3 were higher than at Station 2 and closer to speeds at Station 1.

Net Speed Reductions

The net speed reduction for cars at Station 2 was −1.77 km/hr (−1.09 mph)—a speed increase—which, according to the *t*-test, was not significant. This means that activating one radar

TABLE 2 Speed Statistics at Site 2 (km/hr)

VEHICLE TYPE	CARS			TRUCKS		
STATION	1	2	3	1	2	3
CONTROL DATA						
MEAN SPEED	109.9	86.1	97.7	100.7	79.2	92.2
MIN. SPEED	77.2	67.6	69.2	72.4	64.4	56.3
MAX. SPEED	135.2	115.9	123.9	132.0	94.9	115.9
STANDARD DEVIATION	12.62	14.83	16.46	14.54	12.18	15.63
NO OF OBS.	274	193	187	112	114	97
% EXCEEDING SPEED LIMIT	73.4	95.9	98.9	89.3	75.4	96.9
ONE-RADAR TREATMENT						
MEAN SPEED	108.0	86.1	96.9	99.6	77.2	92.2
MIN. SPEED	78.8	56.3	67.6	74.0	62.7	66.0
MAX. SPEED	144.9	111.0	119.1	122.3	94.9	111.0
STANDARD DEVIATION	15.63	15.11	15.42	13.69	11.33	13.69
NO OF OBS.	149	170	87	88	98	55
% EXCEEDING SPEED LIMIT	65.8	92.4	98.9	87.5	70.4	98.2

did not significantly affect the average speed of cars at Station 2. The net speed reduction for cars at Station 3 was −0.80 km/hr (−0.49 mph), which was also considered not statistically significant. As a result, using one radar was not effective in reducing speeds of cars at this location.

The net speed reductions for trucks were 0.80 and −1.12 km/hr (0.49 and −0.69 mph) at Stations 2 and 3, respectively, with no statistical significance. Thus, the radar was not effective in lowering speeds of trucks at this location. The lack of effectiveness may be explained by the fact that, in less than 0.5 hr, truck drivers with CBs figured out the presence of a drone radar and, consequently, the absence of active speed limit enforcement in the work zone.

Results indicated that using one radar gun at Site 2 did not produce additional reductions on the average speeds of cars and trucks. The effectiveness of one drone radar at Site 2 was not as significant as that at Site 1. The main reasons for these findings may be as follows:

1. Cars and trucks were traveling at lower speeds at Site 2 than at Site 1. For control data at Station 1, cars and trucks traveled 11.0 and 3.7 km/hr (6.8 and 2.3 mph), respectively, faster at Site 1 than at Site 2. At Station 2, cars and trucks traveled 17.0 and 15.0 km/hr (10.3 and 9.3 mph), respectively, faster at Site 1 than at Site 2. Besides, at Site 1, during the control period the average speeds of cars and trucks were 30.2 and 21.7 km/hr (18.8 and 13.5 mph) greater, respectively, than the speed limit at Station 2. However, at Site 2, the average speeds of cars and trucks were only 13.7 and 6.8 km/hr (8.5 and 4.2 mph) greater, respectively, than the speed limit at Station 2. Thus, drivers at Site 2 may not have felt the need for slowing down as strongly as at Site 1.

2. The time period for Site 2 was about three times longer than that for Site 1, and drivers had enough time to figure out who was activating the radar and where it was being activated. In fact, within 0.5 hr some drivers with CB radios were advised of the absence of active speed limit enforcement, and they may not have felt threatened by the radar transmission.

ANALYSIS OF TWO-RADAR EXPERIMENT AT SITE 2 (EXPERIMENT 3)

Description

In Experiment 3, two radar guns were simultaneously activated in the work zone. One radar gun was located near Station 2 and another was close to Station 3. Two radar guns were used to increase the perceived "threat" of police presence and make it difficult for drivers to determine who was transmitting the radar signals. The assumption was that if drivers could not realize whether it was police or drone radar, they might consider the radar as a threat and keep lower speeds.

As in Experiment 2, speeds were measured at three stations, and two CB radios were used to monitor drivers' conversations. Stations 2 and 3 were also monitored to record any unusual behavior that might disturb the normal traffic flow near the stations. The speed limit sign flashing lights were on during data collection, and police were not present in the work zone.

The construction crew was working on the bridge over Route 16 until 3:30 p.m. After 3:30 p.m. (beginning of Interval III), the construction crew left the bridge, resulting in a few work-

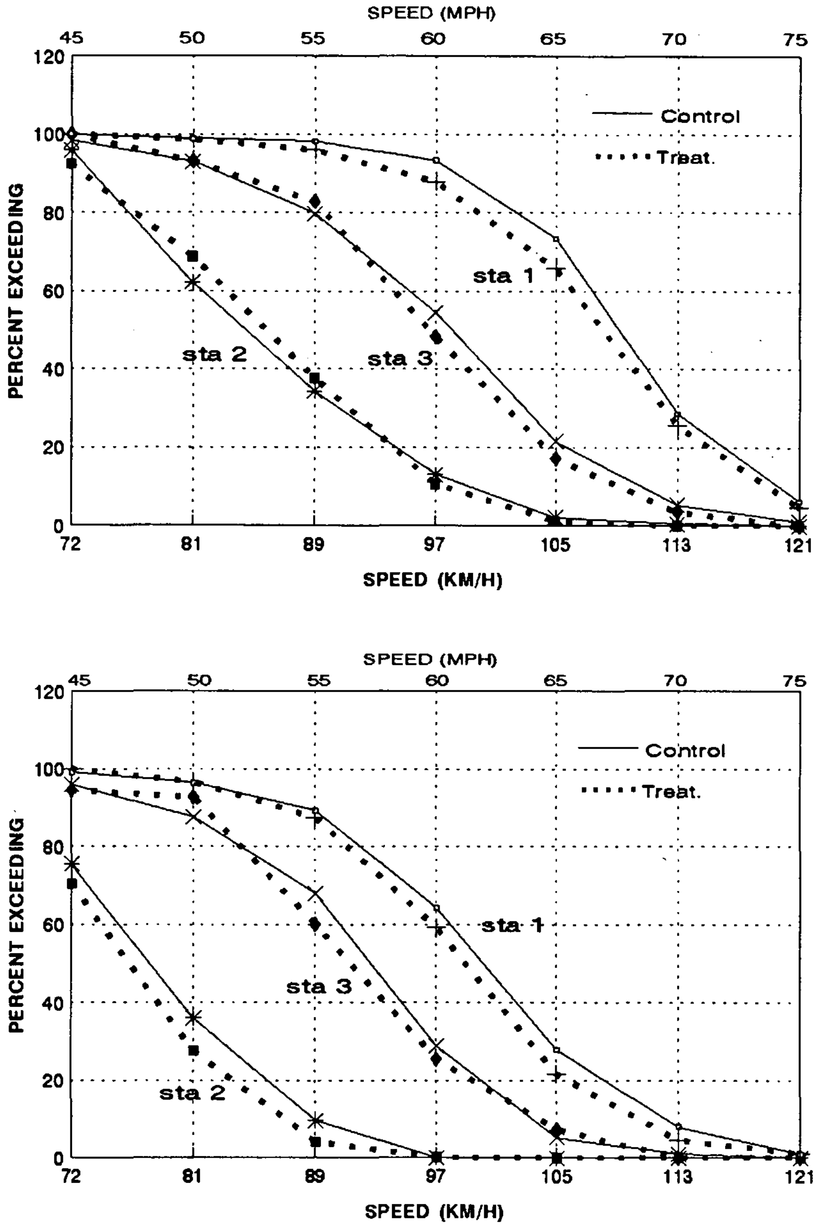

FIGURE 2 Percentage of cars (*top*) and trucks (*bottom*) exceeding a given speed at Site 2, control and treatment data, one-radar treatment.

ers sporadically operating at the site. The flashing lights on the speed limit signs were turned off at the end of Interval III.

The radar near Station 2 was inside a car parked on the northbound direction and aimed at the drivers in the southbound direction. The second radar was placed in a tree located near Station 3 and aimed at the southbound traffic. The tree was selected close to an overpass to give the impression that police might be at the overpass.

Highlights from CB Monitoring

The study team used K- and X-band radar guns and activated them at 1:40 p.m., with the K-band radar placed in the parked car and the X band radar in the tree. From the beginning of this experiment an extensive conversation was going on among drivers trying to determine whether it was a false radar as well as its location. The study team was able to hear only part of their conversations, when drivers were close to Station 2 or 3. An example of the actual conversation, during a 45-min period, heard on the CB near Station 2 demonstrates the extent of the communication and the awareness of radar transmissions:

- 2:17 p.m.: "Smokey Bear doing a loop over here at 189, sitting there in northbound."
- 2:19 p.m.: "Southbound fuzz up here, county mounty."
- 2:30 p.m.: "SB plain gray wrapper."

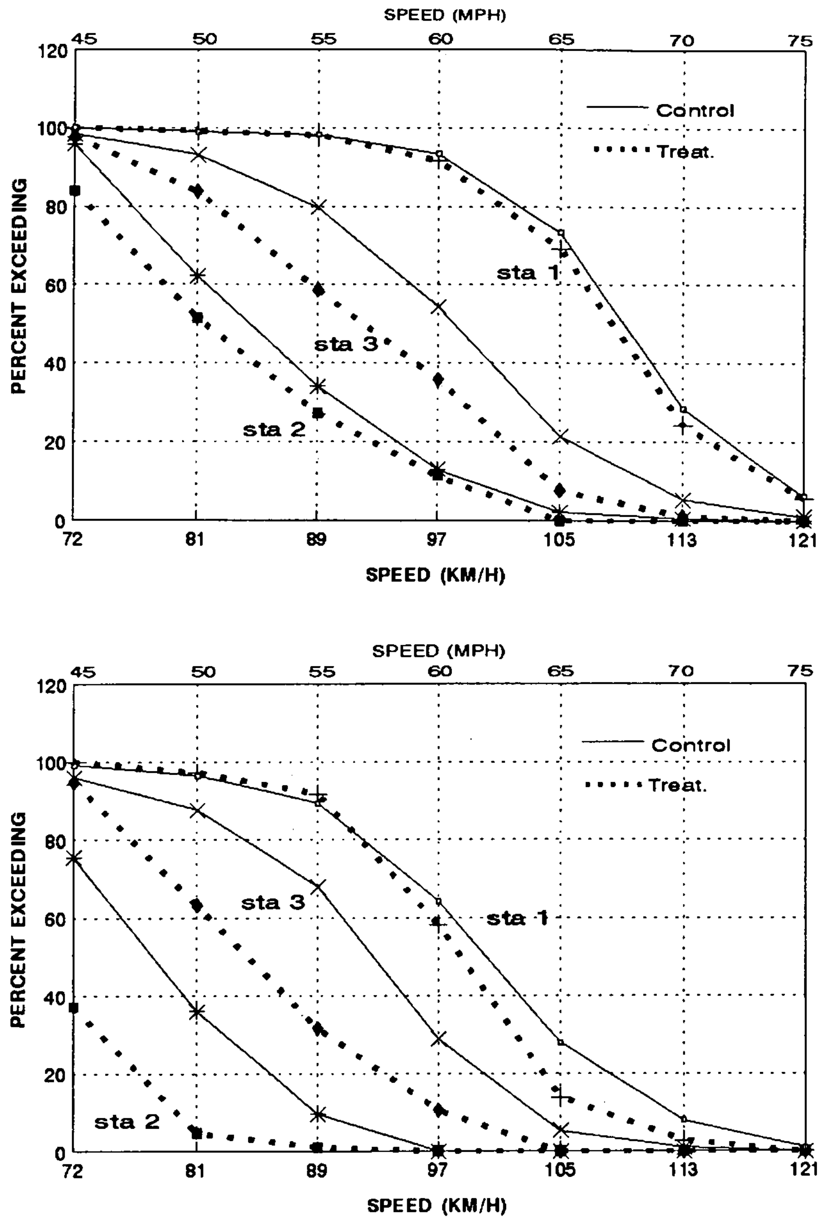

FIGURE 3 Percentage of cars (*top*) and trucks (*bottom*) exceeding a given speed at Site 2, control and treatment data, two-radar treatment, Interval I.

- 2:32 p.m.: "On your side 184 plain brown wrapper they got one of those false radars."
- 2:33 p.m.: "At 190 there is a cop down there but got off."
  "Ah . . . there is a bird dog down here."
  "They have got to have one of them damn radar set up here."
  "Must have been motor home."
  "Negative, wasn't motor home."
  "Something was back there."
- 2:37 p.m.: "Nada 2:44 . . ."
- 2:50 p.m.: "Probably one of those vehicles with damn radar in it."
  "Yah, you probably right, just trying to get a handle on it."
  "It is different radar."
  "Well I think I'll pay attention now."
  "Sure'n I don't pay attention it's a cop."
- 2:54 p.m.: "There may be a couple of them, but I am not sure what the guy is taking about."
- 2:56 p.m.: "Hey my hot dog's crying to tell me something in it."
  "Well one of those dumb guns in the construction truck."
  "A what?"
  "One of those hand-held radar units."
  "Okay 10-4."
- 3:00 p.m.: "My radar detector was going crazy but I slowed down, there is no one out here I missed."
- 3:12 p.m.: "Those two . . . on the side of the road with their walkie-talkies in that construction zone,

just expect every body to slow down cause they got a policeman."

- 3:25 p.m.: "Bird dog barking."
  "Yeah they've got one in their construction truck."
  "10-4."
  "Well I don't know where they got damn things set up but my lights are going red for sure."
  "Yeah but quits right up at that bridge."
  "Ya got a speed picture taken down the road down here."

A similar conversation went on indicating that drivers were still trying to determine the location of the radar and whether the threat was real. From the CB monitoring, it became clear that drivers could not conclude whether it was false radar, the location, or how many had been used.

Data Analysis

Data for the two-radar treatment were collected for 2 hr 45 min and divided into three 55-min periods. These time periods are referred to as Intervals I, II, and III, designating the approximate first, second, and third hours, respectively. This method was used to examine the immediate lasting effects of drone radar. The control data were the same as those of the one-radar treatment at Site 2.

Summary of Speed Characteristics

For all three time intervals the average speeds of both cars and trucks were lower at Station 2 than at Station 1 but higher at Station 3 than at Station 2 (Table 3). The average speeds of cars and trucks were approximately 4.3 to 6.7 km/hr (2.7 to 4.2 mph) and 10.0 to 13.5 km/hr (6.2 to 8.4 mph), respectively, higher than their speed limits at Station 1. At Station 2, the average speeds were about 11.2 to 18.3 km/hr (6.9 to 11.4 mph) and 0.0 to 5.4 km/hr (0.0 to 3.1 mph), respectively, faster than 72 km/hr (45 mph). At Station 3, cars and trucks had average speeds nearly 20.2 to 25.4 km/hr (12.5 to 15.8 mph) and 13.8 to 14.3 km/hr (8.6 to 8.9 mph), respectively, higher than the speed limit of 72 km/hr (45 mph).

Cars and trucks exceeded the speed limits inside and outside the work zone (Figure 3). Between 69 and 81 percent of cars and 90 and 95 percent of trucks traveled faster than their respective speed limits at Station 1. At Station 2, 84 to 94

TABLE 3 Speed Statistics for Two-Radar Treatment at Site 2 (km/hr)

VEHICLE TYPE	CARS			TRUCKS		
INTERVAL	I	II	III	I	II	III
STATION 1						
MEAN SPEED	109.0	110.1	111.4	99.0	102.5	101.1
MIN. SPEED	80.5	80.5	88.5	80.5	83.7	85.3
MAX. SPEED	140.0	135.2	133.6	119.1	120.7	127.1
STANDARD DEVIATION	13.69	14.15	12.49	12.62	11.33	13.63
NO OF OBS.	107	154	122	36	41	50
% EXCEEDING SPEED LIMIT	69.2	77.9	81.1	91.7	95.1	90.0
STATION 2						
MEAN SPEED	83.2	86.3	90.3	72.2	76.1	77.4
MIN. SPEED	66.0	54.7	69.2	56.3	56.3	64.4
MAX. SPEED	104.6	114.3	112.7	91.7	98.2	94.9
STANDARD DEVIATION	15.47	19.70	15.73	10.68	15.99	10.65
NO OF OBS.	124	115	104	43	44	57
% EXCEEDING SPEED LIMIT	83.9	88.7	94.2	37.2	56.8	75.4
STATION 3						
MEAN SPEED	92.2	93.5	97.4	85.8	84.6	86.3
MIN. SPEED	70.8	61.1	70.8	70.8	74.0	70.8
MAX. SPEED	115.9	117.5	119.1	101.4	104.6	101.4
STANDARD DEVIATION	15.94	18.66	16.41	12.70	12.99	11.56
NO OF OBS.	92	94	91	38	36	46
% EXCEEDING SPEED LIMIT	97.8	96.8	98.9	94.7	100.0	97.8

percent of car drivers and 37 to 75 percent of truck drivers were speeding. At Station 3, 97 to 99 percent of cars and 95 to 100 percent of trucks traveled faster than the speed limit of 72 km/hr (45 mph). Cars and trucks increased their speeds after passing the work space as indicated by their higher average speeds and the percentages exceeding the speed limit.

In all three intervals, the percentages of vehicles with excessive speeds were higher at Stations 1 and 3 and lower at Station 2 (Figure 3). The differences between the percentages at Stations 2 and 3 were higher during Interval I than during intervals II and III. Trucks showed similar trends (Figure 3), with percentage differences for Stations 2 and 3 decreasing throughout the three intervals. In Interval I, the percentages were higher at Station 3 than at Station 2. During the two other intervals, percentages at Stations 2 and 3 were closer to each other.

Net Speed Reductions

Net Speed Reduction for Cars

For cars at Station 2, there was a 1.93-km/hr (1.22-mph) net reduction during the first hour (Interval I), no additional speed reduction in the second hour (Interval II), and a 2.73-km/hr (1.69-mph) reduction during the third hour (Interval III). The reductions for Intervals I and II were not statistically significant, but 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).

The main reason for such speed increase might be the absence of crew over the Route 16 bridge during Interval III. The workers left the work site over bridge at the beginning of Interval III, but the speed limit remained 72 km/hr (45 mph) until the end of the interval. The Route 16 bridge was nearly 305 m (1,000 ft) from Station 2, and drivers may have increased their speeds after noticing that there were no workers on the bridge.

For cars at Station 3, the two-radar treatment caused net speed reductions of 4.66, 4.34, and 1.93 km/hr (2.89, 2.69, and 1.19 mph) for Intervals I, II, and III, respectively. Reductions for Intervals I and II were statistically significant, but that for Interval III was not. Drivers may have traveled at higher speeds at Station 3 because they did not see the crew working on the Route 16 bridge. Thus, the drone radar was less effective in Interval III than at Intervals I and II.

Net Speed Reduction for Trucks

For trucks at Station 2, there was a net speed reduction of 5.15, 4.99, and 1.93 km/hr (3.19, 3.09, and 1.19 mph) at Intervals I, II, and III, respectively. Reductions at Intervals I and II were statistically significant, but that at Interval III was not. The results indicated that trucks reduced their speeds at Station 2 when the radar was activated. Drone radar was less effective in Interval III, perhaps because truck drivers did not see any workers on the bridge.

For trucks at Station 3, net speed reductions of 4.66, 9.33, and 6.27 km/hr (2.89, 5.79, and 3.89 mph) were achieved during Intervals I, II, and III, respectively. These reductions were statistically significant, indicating that activating two radar guns caused extra reductions of approximately 5 to 10 km/hr (3 to 6 mph) for trucks. Station 3 was located after the work space where drivers tended to increase their speeds. Besides, during Interval III truck drivers may have increased their speeds at Station 3 because they did not see any crew working on the bridge.

CONCLUSIONS

Speed reduction effects of continuously transmitting drone radar signals at two construction sites for five time periods are summarized in Figure 4. Experiment 1 indicated that when one drone radar was used for a short period (less than 1 hr) where vehicles were going very fast inside and outside the work zone, speed reductions of nearly 13 to 16 km/hr (8 to 10 mph) were obtained. These reductions were for short time periods and may not represent typical speed reductions due to drone radars.

The results of Experiment 2 indicated that using one radar when drivers knew that it was drone radar did not reduce the average speed of cars or trucks. Also, the decrease in the percentage of vehicles with excessive speeds was relatively small.

The results of Experiment 3 indicated that there were additional speed reductions when drivers could not determine whether it was drone radar. The additional speed reductions were consistent for trucks but not for passenger cars. In five out of six cases, trucks showed statistically significant net speed reductions of 5 to 10 km/hr (3 to 6 mph). Cars showed statistically significant net reductions of 5 km/hr (3 mph) only in two out of six cases. One reason the drone radar was not effective on cars and was less effective on trucks during Interval III might be the absence of crew over the Route 16 bridge during Interval III. Another reason may be that car drivers do not use CB radios and radar detectors as much as truck drivers do. Pigman et al. (*3*) found that only 11 percent of cars (compared with 42 percent of trucks) used radar detectors. The speed reduction effects of drone radar did not diminish on trucks over a period of approximately 3 hr.

The differences in the percentage of vehicles exceeding the speed limits during the two-radar treatment and the control period indicated that at Stations 1 and 3 there were no significant reductions due to the use of radar. However, at Station 2, cars and trucks had speed reductions that decreased over time. The reductions were 12, 7, and 2 percent for cars and 38, 18, and 0 percent for trucks in Intervals I, II, and III, respectively.

Drivers with a radar detector 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 and attention in traveling through work zones.

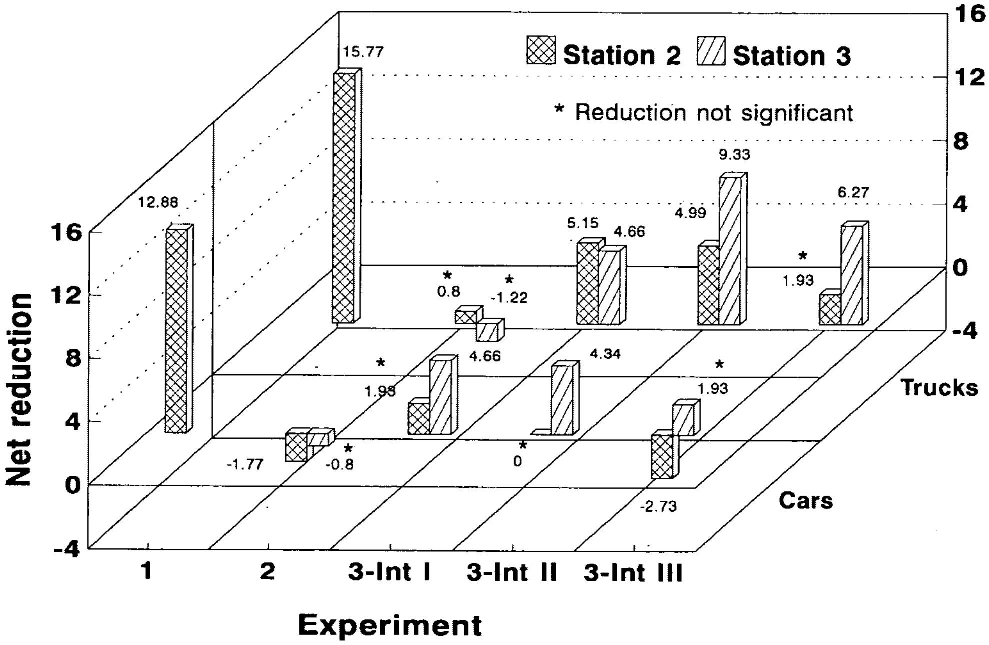

FIGURE 4 Net speed reductions (km/hr), Experiments 1, 2, and 3.

RECOMMENDATIONS

Drone radar may be used effectively to slow down a speeding driver who has a radar detector or uses a CB radio. However, the use of drone radar over a longer period of time diminishes its effects because drivers may detect the absence of active speed enforcement. Therefore, drone radar can be most effective during short periods when drivers have not identified the source of radar transmissions. The number of radars used directly affected the drivers' responses. 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 that drivers are kept "off balance" as to when the radar is real and when it is drone.

This study used conventional radar guns, which are commonly used by law enforcement officers. New radars use laser light pulses instead of radio waves and are called lidar (light detection and ranging). They are also called laser radars because they use laser light pulses. Conventional radars transmit radio waves and cover a wider detection area. However, lidars transmit a very narrow light beam that can be aimed at a specific vehicle in a traffic stream. The speed reduction effects of lidar guns need to be studied.

REFERENCES

1. *Manual on Uniform Traffic Control Devices.* FHWA, U.S. Department of Transportation, 1988.
2. D. L. Warren. Speed Zoning and Control. In *Synthesis of Safety Research Related to Traffic Control and Roadway Elements,* Vol. 2, FHWA-TS-82-233, Dec. 1982.
3. J. G. Pigman, K. R. Agent, J. A. Deacon, and R. J. Kryscio. Evaluation of Unmanned Radar Installations. Presented at 68th Annual Meeting of the Transportation Research Board, Washington, D.C., 1989.
4. S. H. Richards, R. C. Wunderlich, and C. L. Dudek. Field Evaluation of Work Zone Speed Control Techniques. In *Transportation Research Record 1035,* TRB, National Research Council, Washington, D.C., 1985.
5. G. L. Ullman. The Effect of Radar Transmissions Upon Traffic Operations at Highway Work Zones. Presented at the 70th Annual Meeting of the Transportation Research Board, Washington, D.C., 1991.
6. R. F. Benekohal, P. T. V. Resende, and W. Zhao. Speed Reduction Effects of Drone Radar in Work Zones. FHWA-IL-UI-238. March 1992.
7. *SAS/STAT User's Guide, Release 6.03.* SAS Institute, Inc., Cary, N.C., 1988.
8. G. E. Box, W. G. Hunter, and J. S. Hunter. Statistics for Experimenters. John Wiley & Sons, New York, 1978.

Publication of this paper sponsored by Committee on Traffic Safety in Maintenance and Construction Operations.