

# Effect of Radar Drone Operation on Speeds At High Crash Risk Locations

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At highway construction and maintenance work zones and other locations where roadway alignment, road surface, and traffic flow conditions have contributed to high crash rates, crash risk may be reduced by lower and more uniform speeds. The use of unattended (drone) radar has been found to reduce the mean speed of vehicles and the number traveling at very high speeds. Drivers using radar detectors to warn of police speed enforcement activities respond to the warning and slow down, as do drivers of nearby vehicles. Speeds were measured with and without radar drones in operation at 12 construction and maintenance work zones and high crash locations in Missouri. It was found that mean speeds were moderately lower when radar was operating, and this effect was slightly greater for tractor-trailers than for passenger vehicles, although not significantly so at most locations. However, moderate reductions in mean speed were associated with more meaningful reductions in the number of vehicles exceeding the speed limit by more than 10 mph (17 kph), especially among tractor-trailers.

At hazardous highway locations where excessive speed contributes to crashes, reducing speeds is likely to be an effective countermeasure. Crash damage and injury severity have been found to increase with the square of velocity (1), and the risk of death in a crash has been shown to increase with the fourth power of the change in velocity (or the square of the energy dissipated) in a crash (2). Energy increases with the square of speed, and greater speed reduces the time and distance available to execute a crash avoidance maneuver and increases the distance needed to stop. In a study of crashes in Kentucky, speed was identified as a factor in almost 9 percent of all crashes and 37 percent of fatal crashes (3).

Highway construction and maintenance work zones are known to be especially hazardous locations where excessive speeds and driver inattention or distraction may contribute to crashes. Unanticipated changes in traffic speed, lane closures, and altered roadway alignment create conditions that increase the likelihood of a crash. Construction equipment and worker activities may distract a driver's attention, and temporary or absent road markings can render the proper path difficult to discern. Construction barricades and other traffic channeling devices may themselves become roadway hazards. In 1991 602 crashes caused 680 deaths at construction and maintenance work zones (4). FHWA guidelines stress that traffic movement in construction and maintenance work zones should be inhibited as little as practicable and that reduced speed zoning should be avoided as much as possible (5). However, preventing excessive speeds and large speed differences between vehicles helps alleviate some of the conditions that may lead to a crash. The characteristics of work zones where speed reductions are appropriate and the extent to which speeds should be reduced

have been investigated previously (6). It was recommended that speed limits be reduced only where careful analysis indicated they were warranted, that maximum speed reductions be chosen according to roadway design and operating characteristics, and that active speed control (such as visible enforcement) be used where drivers are unwilling or unable to comply with posted work-zone speed limits.

Lower and more uniform speeds may also reduce the crash risk at other locations where roadway alignment, road surface, and traffic flow conditions have contributed to high crash rates. Although speed limits have been shown to affect speeds on freeways, many drivers exceed posted speed limits (7). Visible or perceived police enforcement tends to reduce speeds, especially in the immediate vicinity of those enforcement activities (8). Police radar is a widespread and effective speed enforcement tool.

To evade speeding citations, many drivers, especially tractor-trailer drivers, use radar detectors and slow down before being apprehended. Users of radar detectors have been found to drive faster than nonusers (9-11), to be more likely to be involved in crashes (12), and to slow down when they encounter police radar (13,14). Manned and unmanned (or drone) radar have been used to slow users of radar detectors. When radar detector-equipped vehicles slow down, other nearby vehicles also slow down. Research has revealed that about 15 percent of drivers of vehicles not equipped with radar detectors claim to adjust their vehicles' speed to that of a nearby radar detector-equipped vehicle (15). Drone radar has been found to effectively reduce the number of vehicles traveling at excessive speeds on roads with high crash rates, and especially to reduce mean speeds of the fastest vehicles approaching and within work zones (8,16). NHTSA has recognized the use of such drone radar operations as a speed deterrent and issued guidelines for their use (4).

The Federal Communications Commission (FCC), which regulates radar-emitting devices, requires them to conform to certain design and performance specifications. Some of the requirements are for unattended radar devices to be capable of transmitting and receiving a radar signal and to use the return signal to count vehicles or trigger a light or some sort of speed display. Low-power devices of this type are referred to as field disturbance sensors; full-power police radar units may also be used. Unattended radar units that do not use the return signal have been prohibited by the FCC.

In the present study, speeds were measured at roadways in Missouri that were identified by police and traffic engineering officials as having traffic speeds too high for safe operations. Drone radar units were deployed at these sites. The study sought to determine the effect of the radar drones on speeds in the vicinity of four types of hazardous locations: rural Interstate construction zones, rural and urban temporary work zones, rural Interstate high crash locations, and urban Interstate high crash locations.

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## METHOD

### Site Selection and Characteristics

The 12 study sites were selected from a list of candidate high crash locations and work zones provided by the Missouri Highway and Transportation Department Construction Division, the Missouri State Highway Patrol, and the Kansas City Maintenance Department. These were long-term construction zones on 65 mph (105 kph) rural Interstates [posted at 45 mph (72 kph) in the work zone], short-term maintenance zones on 55 mph (88 kph) urban and rural highways [posted at 45 mph (72 kph) in the work zone], high crash frequency locations on rural 65 mph (105 kph) Interstates, and high crash frequency locations on urban 55 mph (88 kph) Interstates. The normal speed limit for trucks on rural Interstates in Missouri is 60 mph (96 kph). Police accident reports were reviewed to ensure that excessive speed was a contributing factor at each candidate high crash site. Study sites were selected from candidates with relatively level terrain and adequate sight distances so that road geometry (such as sharp curves or steep grades) was not likely to have been a factor in the crashes or to influence speeds. Eleven sites had two lanes of traffic in each direction; one had three lanes. Average daily traffic (both directions combined) ranged from 20,000 to 70,000 vehicles per day. Sites were located according to the county's roadway records using the county road log milepoints. Site locations and characteristics are summarized in Table 1.

At each site, speed data for one direction of traffic were collected at two stations, as shown in Figure 1. One station was situated where a speed reduction was desired. The drone radar was also placed at this station, emitting radar in the upstream direction. For long-term construction zones, the radar drone station coincided with the

beginning of the lane closure taper. At temporary work zones, the drone radar was at the first 45 mph (72 kph) reduced speed limit sign, located about 0.4 mi (0.6 km) upstream of the lane closure. At high crash locations, this station was near the county road milepost identified on the police accident report. The downstream station (out of range of the radar drone) was located well beyond where an initial speed reduction should have occurred but where reduced speeds are still important. At long-term construction zones, this was within the work zone, 0.2 to 0.8 mi (0.3 to 1.3 km) downstream of the drone radar. At short-term work zones, it was also within the work zone, 0.2 to 0.6 mi (0.3 to 1.0 km) downstream of the drone radar, near the beginning of the temporary lane closure. At high crash locations, the downstream measurement station was 0.4 to 0.8 mi (0.6 to 1.3 km) beyond the drone radar. The site types are shown in Figure 1.

Speed data were also collected at a third station, located at least 0.4 mi (0.6 km) upstream of the drone radar, where it was expected that vehicles would have been beyond the range of (and therefore uninfluenced by) the radar. These observations were intended to provide baseline speed data. It was later discovered that, because of variations in radar operating characteristics and radar detector sensitivity, vehicles at some of these upstream stations may have been within the radar's range. Because it was unclear whether these data were influenced by radar, they were not analyzed further.

Three different manufacturers' drone radar units were used in this study. Each type of drone unit was deployed at one long-term construction zone, one temporary work zone, and two high crash locations. Drones were mounted approximately 8 ft (2.4 m) above the pavement at the roadway edge at each site, with the mounting assembly (but not the drone) painted with camouflage colors to make it less conspicuous. Drones were operated on a 1-hr-on,

TABLE 1. Radar Drone Data Collection Site Characteristics

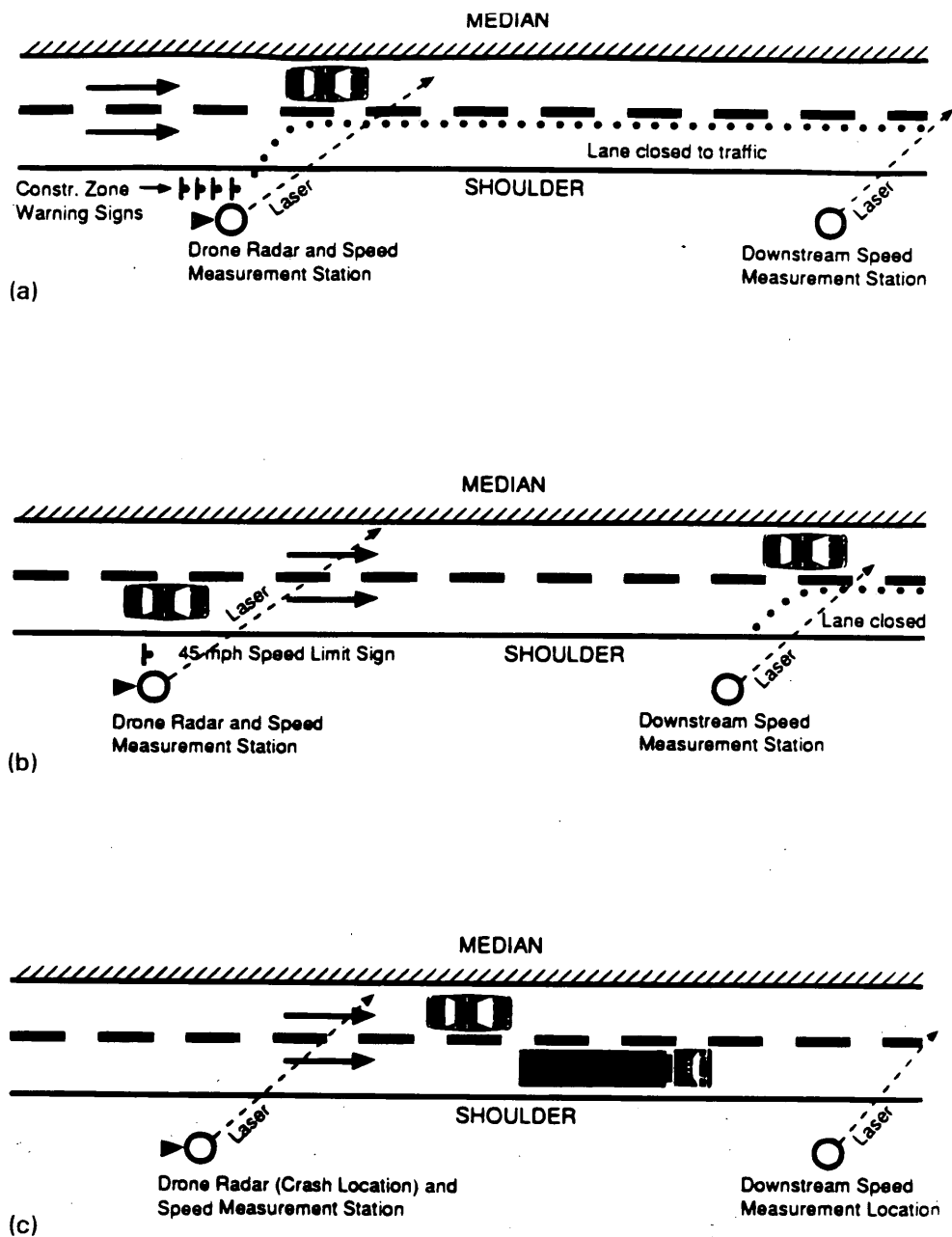
Site No.	Route	County	Urban or Rural	Speed Limit (mph)	Average Daily Traffic*** (veh/day)	County Road Log Milepoints	
						Drone	Downstream
<b>Rural Interstate Construction Zones</b>							
1	I-70 (W)	Cooper	Rural	65	20,880	10.2	10.0
2	I-70 (W)	Callaway	Rural	65	22,645	24.1	23.4
3	I-29 (N)	Platte	Rural	65	20,040	18.4**	19.2**
<b>Rural/Urban Temporary Work Zones</b>							
4	US-71 (S)	Cass	Rural	55	22,480	17.3	17.7
5	I-435 (S)	Jackson	Urban	55	70,370	58.3**	58.8**
6	I-470 (W)	Jackson	Urban	55	42,110	5.6**	5.4**
<b>Rural/Interstate High Crash Locations*</b>							
7	I-70 (E)	Montgomery	Rural	65	21,640	1.1	1.5
8	I-70 (W)	Callaway	Rural	65	23,670	11.4	10.9
9	I-70 (W)	Boone	Rural	65	27,075	7.7	7.0
10	I-70 (W)	Jackson	Rural	65	35,510	25.1	24.7
<b>Urban Interstate High Crash Locations*</b>							
11	I-35 (S)	Clay	Urban	55	46,590	18.4	19.2
12	I-35 (S)	Clay	Urban	55	41,865	20.1	19.4

\* 60 mph (100 kph) for heavy trucks on rural interstates.

\*\* Interstate mile post.

\*\*\*1992, both directions.

1 mph = 1.6 kph; 1.6 km



**FIGURE 1** Schematic of study sites: (a) long-term construction zone layout, (b) temporary work-zone layout, and (c) high crash location layout.

1-hr-off basis throughout the data collection period, instead of on a longer-term before and after schedule. This was done to increase the likelihood that periodic changes in traffic flow characteristics not related to the drones (e.g., reduced speeds because of rain one day but fair weather and higher speeds on other days) would be equally represented in the two conditions, thus allowing comparison of the effects of drones on speeds.

#### Data Collection

Speeds of a random sample of vehicles were measured from 9:00 a.m. to 5:00 p.m. on a single day at each site. Data were col-

lected during the full 8-hr period at each long-term construction work zone and high crash location; at temporary, maintenance work zones, speeds were measured while the work zone was in place (4 to 6 hr within the 9:00 a.m. to 5:00 p.m. period). Data were not collected during periods when precipitation may have affected speed.

Speeds were measured by using a commercially available laser speed measurement system, which determines speed by measuring the time of flight of very short pulses of infrared light. Lasers of this type are not detectable by radar detectors. Although laser detectors are commercially available, they are not widely used and have been found to be relatively ineffective in field testing on a closed course

(17). Lasers are used for speed enforcement by a growing number of police departments.

Speeds were sampled during the first 45 min of each hour. Vehicles were systematically sampled by selecting the next vehicle, in any of the studied lanes that crossed the laser's line of sight after the previously sampled vehicle's speed was recorded. At each site, data were simultaneously collected at each of the measurement stations. An observer located beyond the right shoulder measured speeds of vehicles with the laser aimed 500 to 1,000 ft (150 to 300 m) downstream of the observer's station. Traffic volume was counted each hour for 10 min following each speed data collection period. Observers also recorded the time, location, and nature of unusual events, such as vehicle breakdowns, that could have influenced traffic speeds. By monitoring drivers' comments on citizen-band radios, observers confirmed that the radar drone's signal had been detected by users of radar detectors.

### Analysis

Measured speeds were divided by the cosine of the angle between a vehicle's heading and the laser's line of sight to compensate for cosine error. Frequency counts of speed observations, mean speeds, and percentages of vehicles exceeding the speed limits by various amounts were computed by vehicle type (passenger car, pickup, van, utility vehicle, tractor-semitrailer, tractor-double trailer, straight truck, bus, towed vehicle, and others), measurement station (upstream or downstream), and drone condition (off or on) for each site. The main effects and interactions of the drone radar condition and vehicle type on speed were determined separately for each measurement station and site with the SAS General Linear Model procedure (18). The effects of drone radar on the distribution of the

fastest vehicles [those exceeding the speed limit by more than 10 mph (16 kph)] were determined by using the chi-square statistic.

### RESULTS

A total of 20,516 observations of vehicle speeds were made at the speed reduction and drone radar and downstream measurement stations. As shown in Table 2, approximately three-fourths were of passenger cars, pickups, vans, and utility vehicles, and nearly one-fifth were tractor-semitrailer and double trailer combinations. The remainder (straight trucks, buses, towed vehicles, and others) made up less than one-twentieth of the sample. Because the operating characteristics and radar detector use among the vehicles in this latter group typically vary widely (9,10) and because the number of observations at each station at each site was small, these observations were not included in further analyses of speeds.

Mean speeds and percentages exceeding the speed limits by more than 10 mph (16 kph) with the radar drones on and off are shown in Table 3 for each station at each site for the combined group of passenger cars, pickups, vans, and utility vehicles and in Table 4 for the combined group of tractor-trailers (tractor-semitrailer and double trailer trucks).

Overall, speeds of all vehicle types were higher than the posted or reduced speed limits. Passenger vehicle speeds tended to be higher than truck speeds. Speeds were generally lower when the radar drones were on. The effect of radar drones on speeds was slightly greater for trucks than for passenger vehicles but was significantly so ( $\alpha < 0.05$ ) at only two sites: the downstream location at Site 11, an urban Interstate high crash location, and the drone location at Site 4, a rural/urban temporary work zone.

The following sections discuss the effects of drones at each site type.

TABLE 2 Number of Observations by Vehicle and Site Type

Type	Site Type				Total
	Long-term Construction	Short-term Work Zone	Rural High Crash	Urban High Crash	
<b>Passenger Vehicles</b>					
Passenger cars	2,478	1,651	4,058	2,101	10,288
Pickups, vans, utility vehicles	1,111	1,147	1,825	1,274	5,357
<b>Tractor-Trailers</b>					
Tractor-semi-trailer trucks	376	1,477	1,385	521	3,759
Tractor-double trailer trucks	64	18	107	14	203
<b>Other Vehicles</b>					
Straight trucks delivery trucks	87	94	185	94	440
Other (bobtail, tractor, bus, towed vehicle, etc.)	133	68	210	58	469
<b>Total</b>	<b>5,386</b>	<b>3,318</b>	<b>7,750</b>	<b>4,062</b>	<b>20,516</b>

TABLE 3 Measured Speeds of Passenger Cars, Pickups, Vans, and Utility Vehicles (mph)

Site	Drone	Measurement Location					
		Drone			Downstream		
		No.	Mean	Percent High Speed**	No.	Mean	Percent High Speed**
<b>Rural Interstate Construction Zones</b>							
2	off	289	55.6	55	255	48.3	18
	on	212	55.1	50	261	47.0	12
3	off	364	65.3	93	277	57.8	68
	on	346	62.9	90	270	56.4	57
13	off	348	62.4	88	309	55.3	49
	on	329	61.5	87	365	53.7	38
<b>Rural/Urban Temporary Work Zones</b>							
9	off	209	60.3	85	211	57.7	66
	on	234	59.9	85	208	57.6	66
10	off	323	60.7	82	285	57.5	60
	on	227	57.3	66	256	54.4	44
14	off	181	56.5	62	174	53.8	40
	on	202	57.1	60	252	54.4	41
<b>Rural Interstate High Crash Locations</b>							
4	off	299	68.8	8	350	69.0	8
	on	294	67.1	2	295	67.2	4
5	off	369	67.0	5	310	66.9	6
	on	388	66.2	3	362	66.2	6
6	off	354	66.2	6	456	66.2	4
	on	438	66.3	4	414	67.0	4
12	off	363	66.1	2	367	66.0	3
	on	430	65.9	2	394	64.9	2
<b>Urban Interstate High Crash Locations</b>							
8	off	416	61.0	18	462	63.0	29
	on	411	60.3	16	475	62.9	30
11	off	374	61.2	22	408	60.8	20
	on	400	60.4	15	429	60.8	20

1 mph = 1.6 kph

\*\* Exceeding speed limit by more than 10 mph (16 kph).

### Rural Interstate Long-term Construction Zones

At Sites 1, 2, and 3, the usual posted 65 mph (105 kph) speed limit was reduced to a posted speed limit of 45 mph (72 kph). Although mean speeds for passenger vehicles were generally at or below 65 mph (105 kph), they exceeded the 45 mph (72 kph) limit by 10 to 20 mph (16 to 32 kph) at the drone stations and by a least 10 mph (16 kph) at two downstream stations with drone radar off

or on. Tractor-trailers exceeded the reduced speed limit by up to 15 mph (24 kph) at the drone stations and by nearly 10 mph (16 kph) at two of the downstream stations with the radar off or on.

Regardless of the drone radar operating condition, mean speeds of passenger vehicles were higher than those for trucks at all measurement stations, as shown in Figure 2.

Mean speeds of passenger vehicles were 0.5 to 2.4 mph (0.8 to 3.9 kph) lower and of tractor-trailers were 0.6 to 3.6 mph (1.0 to

TABLE 4 Measured Speeds of Tractor-Trailers (mph)

Site	Drone	Measurement Location					
		Drone			Downstream		
		No.	Mean	Percent High Speed**	No.	Mean	Percent High Speed**
<b>Rural Interstate Construction Zones</b>							
2	off	145	51.3	31	136	47.5	12
	on	138	49.5	15	152	46.0	7
3	off	120	60.2	84	170	54.6	46
	on	150	56.6	59	153	52.3	30
13	off	78	57.7	69	103	53.2	33
	on	89	56.7	64	107	52.6	32
<b>Rural/Urban Temporary Work Zones</b>							
9	off	40	59.5	82	44	54.0	39
	on	59	56.0	52	52	52.0	33
10	off	42	54.6	48	36	52.3	31
	on	32	53.7	34	35	50.1	11
14	off	16	53.4	38	10	50.5	20
	on	15	52.0	40	13	52.4	23
<b>Rural Interstate High Crash Locations***</b>							
4	off	121	63.2	10	116	63.6	9
	on	140	61.4	0	113	61.9	4
5	off	103	62.2	4	106	57.9	2
	on	70	60.4	3	88	56.8	0
6	off	81	63.1	4	71	62.0	3
	on	95	62.3	3	60	63.1	3
12	off	90	61.8	3	64	60.1	0
	on	90	60.3	1	84	59.9	0
<b>Urban Interstate High Crash Locations</b>							
8	off	86	59.2	9	73	62.6	23
	on	77	57.2	15	63	60.7	18
11	off	52	60.5	21	59	58.5	8
	on	58	59.5	10	67	57.4	6

1 mph = 1.6 kph

\*\* Exceeding speed limit by more than 10 mph (16 kph).

\*\*\* 60 mph (97 kph) speed limit for trucks.

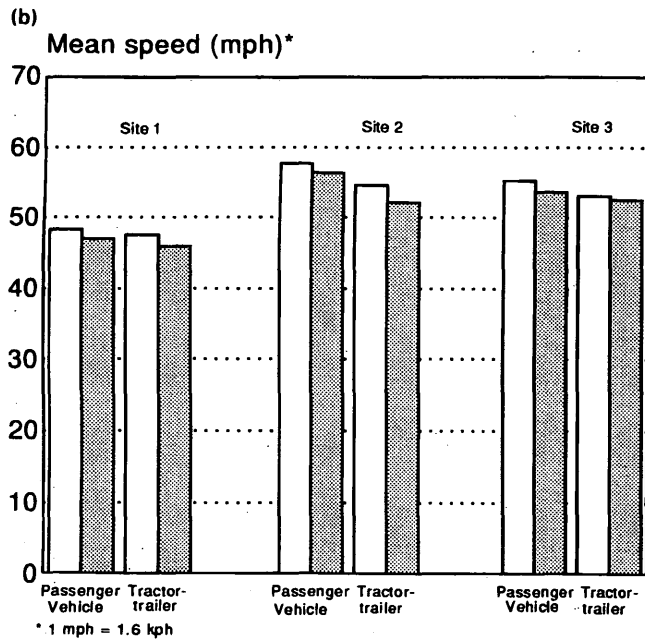
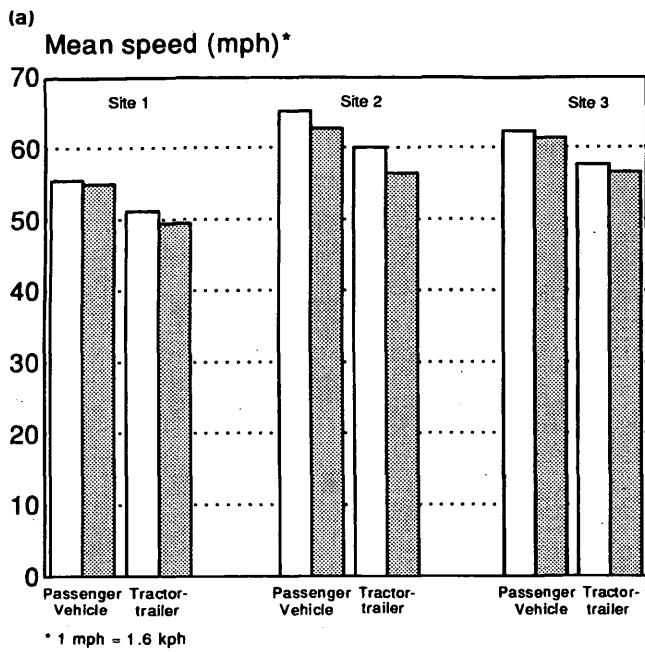
5.8 kph) lower when drone radar was on than when it was off. The differences were significant for two of three drone radar stations (the third was nearly significant) and for all downstream stations within the work zone. The effect of the drones was not statistically different for passenger vehicles and trucks.

The proportion of very fast vehicles was lower with radar on in every case, as shown in Figure 3. Proportions of passenger vehicles exceeding the speed limit by more than 10 mph (16 kph) were significantly (chi-square  $p < 0.05$ ) lower at the downstream location at Sites 2 and 3. Excessive speeding was significantly reduced

among tractor-trailers at drone stations at Sites 1 and 2 and at Site 3 downstream, and the differences were nearly significant at Site 1 downstream for passenger vehicles and trucks.

#### Rural and Urban Freeway Temporary Work Zones

A temporary speed limit of 45 mph (72 kph) was in force at Sites 4, 5, and 6, which were normally posted at 55 mph (88 kph). Mean speeds of passenger vehicles and trucks are shown in Figure 4. In

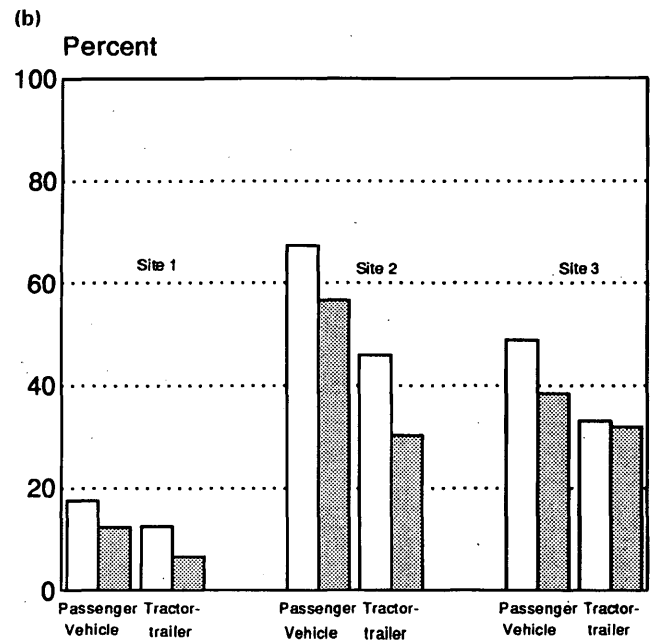
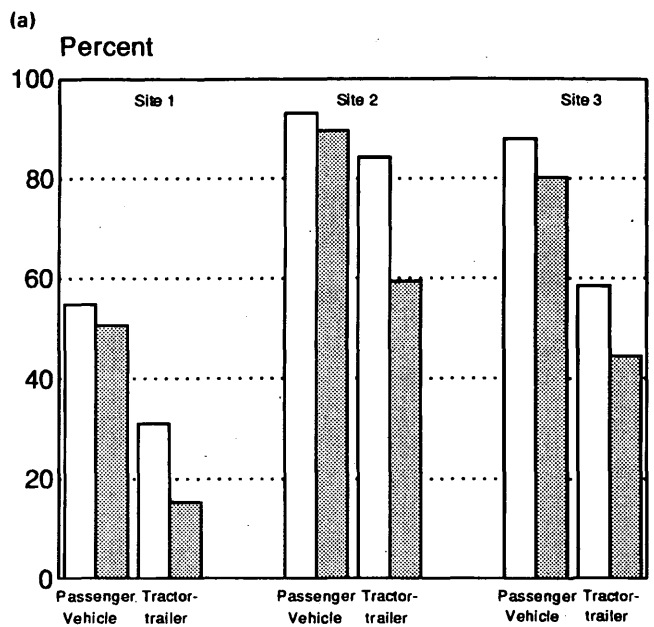


**FIGURE 2** Mean speeds for passenger vehicles and tractor-trailers at long-term rural construction zones: (a) drone location and (b) downstream location (shaded bar, radar on; white bar, radar off).

most cases, the mean speed of passenger vehicles exceeded the normal speed limit at upstream and downstream stations, and in all cases, passenger vehicle and heavy truck mean speeds exceeded the reduced speed limit, regardless of whether drone radar was off or on.

Passenger vehicle mean speeds were significantly higher than truck mean speeds at upstream and downstream stations at each of the three temporary work zones, with drone radar either off or on.

Although passenger vehicle mean speeds were lower when the radar drones were on at the upstream and downstream stations at



**FIGURE 3** Percentage over speed limit by more than 10 mph (16 kph) for passenger vehicles and tractor trailers at long-term rural construction zones: (a) drone location and (b) downstream location (shaded bar, radar on; white bar, radar off).

Sites 4 and 5, they were higher at Site 6. Mean speeds were also lower for heavy trucks at the upstream stations at Sites 4, 5, and 6 and at the downstream locations at Sites 4 and 5, but were higher at downstream Site 6. The differences (for both vehicle types combined) were significant at only Sites 4 and 5 upstream and Site 5 downstream.

The proportions of vehicles exceeding the speed limit by more than 10 mph (16 kph) were more often lower when radar was on, as shown in Figure 5. The differences were significant for passenger

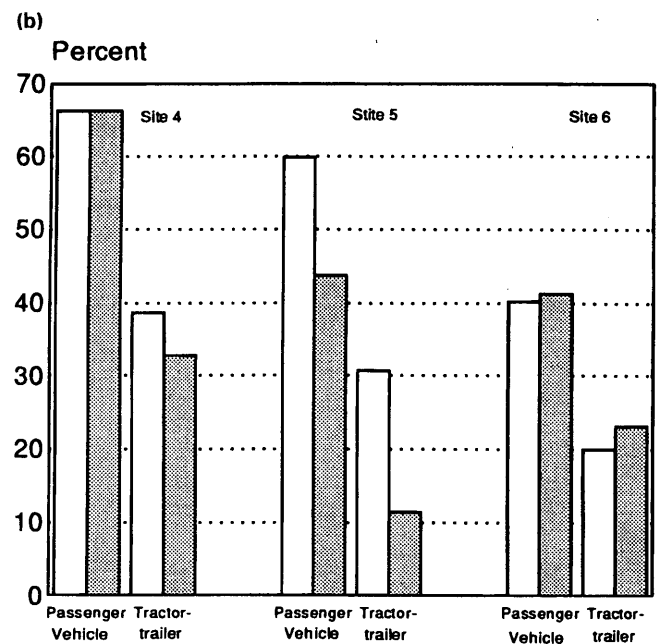
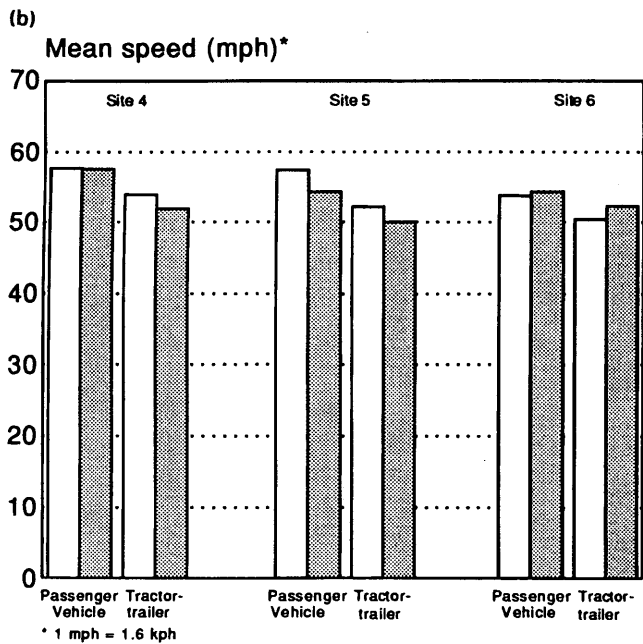
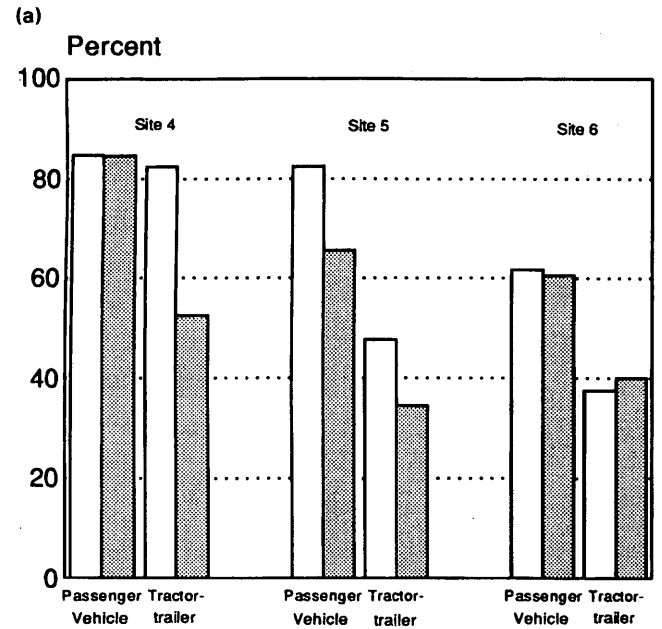
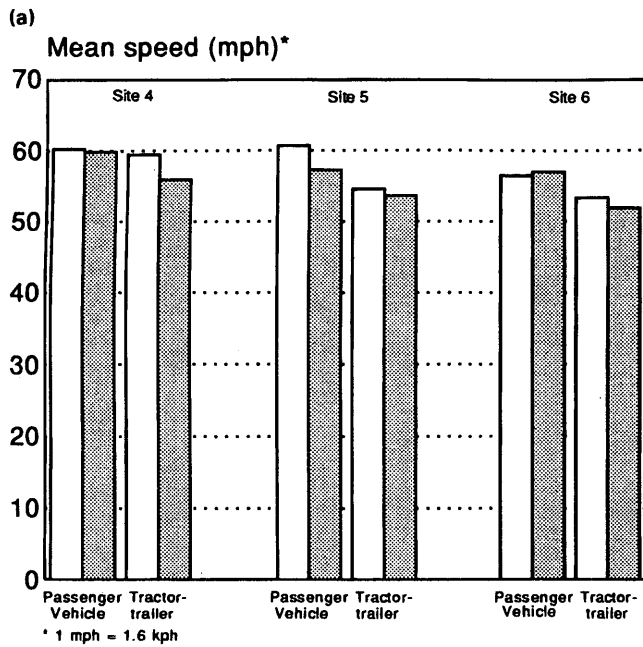


FIGURE 4 Mean speeds for passenger vehicles and tractor trailers at rural/urban temporary work zones: (a) drone location and (b) downstream location (shaded bar, radar on; white bar, radar off).

FIGURE 5 Percentage over speed limit by more than 10 mph (16 kph) for passenger vehicles and tractor-trailers at rural/urban temporary work zones: (a) drone location and (b) downstream location (shaded bar, radar on; white bar, radar off).

vehicles at the drone and downstream locations at Site 5 and for trucks at the drone location at Site 4 and the downstream location at Site 5.

**Rural Interstate High Crash Locations**

Passenger vehicle mean speeds were at or slightly above the posted 65 mph (105 kph) speed limit at Sites 7, 8, 9, and 10, regardless of

whether the drone radar was on or off. Tractor-trailer mean speeds were more than the 60 mph (97 kph) truck speed limit at all drone stations and most downstream stations by up to 3.6 mph (5.8 kph). Tractor-trailer speeds were significantly lower than passenger vehicle speeds at the upstream and downstream stations at all four sites. When the radar was on, mean speeds were 0.2 to 1.8 mph (0.3 to 2.9 kph) lower among passenger vehicles at Sites 7, 8, and 10; however, speeds were 0.1 to 0.8 mph (0.2 to 1.3 kph) higher at Site 9. Among tractor-trailers, mean speeds were 0.2 to 1.8 mph (0.3 to



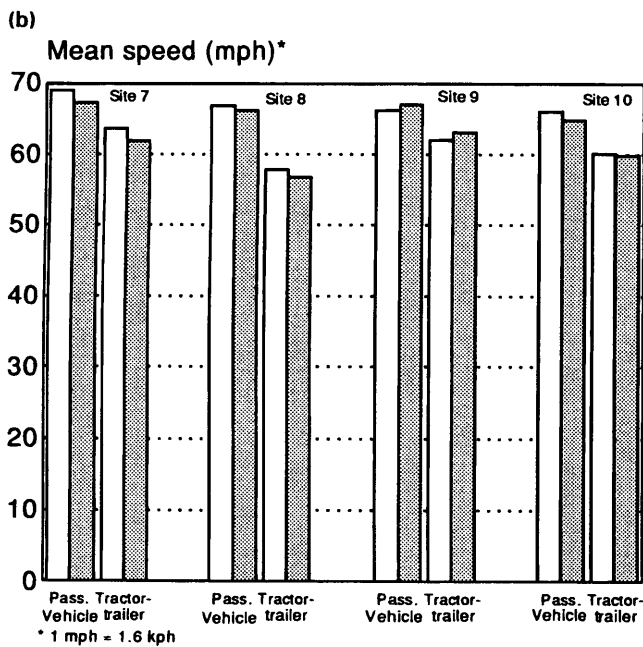
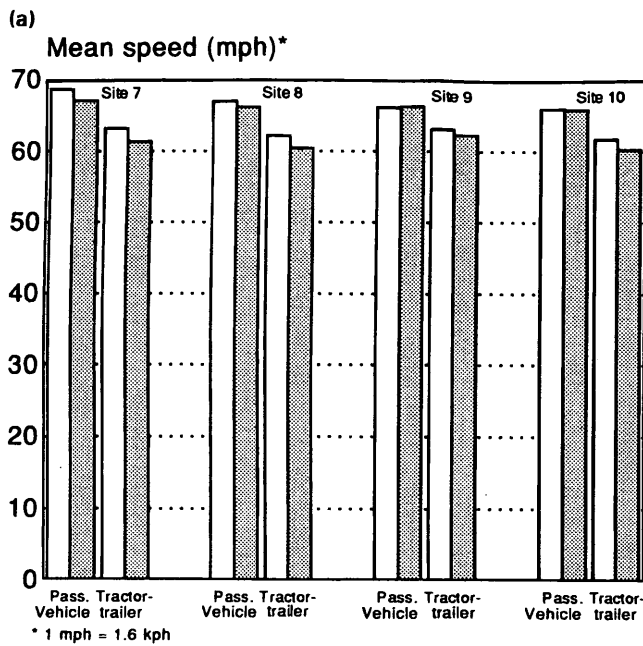


FIGURE 6 Mean speeds for passenger vehicles and tractor-trailers at rural Interstate high crash sites: (a) drone location and (b) downstream location (shaded bar, radar on; white bar, radar off).

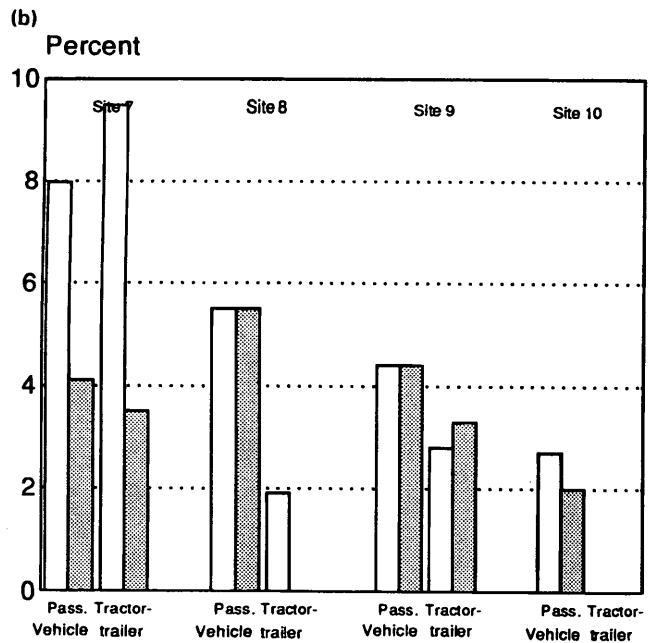
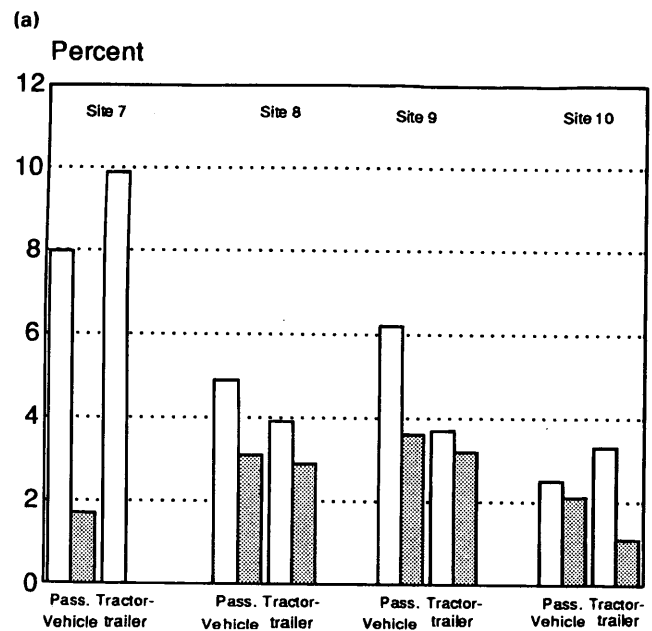


FIGURE 7 Percentage over speed limit by more than 10 mph (16 kph) for passenger vehicles and tractor-trailers at rural Interstate high crash sites: (a) drone location and (b) downstream location (shaded bar, radar on; white bar, radar off).

2.9 kph) lower at both stations at all four sites with the radar on. The speeds were significantly different for all vehicles combined at upstream stations at Sites 7, 8, and 10, at the downstream station at Site 7, and nearly significant downstream at Sites 8 and 9 (Figure 6).

The proportion of high-speed passenger vehicles was in all but two cases lower when radar drones were on, significantly so at the drone and downstream locations at Site 7, as shown in Figure 7. The proportion of high-speed tractor-trailers was reduced at most mea-

surement stations, significantly so at the drone location (and nearly so at the downstream station) at Site 7.

#### Urban Interstate High Crash Locations

Passenger vehicle and tractor-trailer mean speeds exceeded the 55 mph (88 kph) speed limit at the drone and downstream stations

with drone radar off or on at Sites 11 and 12. Unlike at other sites, speeds at Site 11 increased markedly [about 3 mph (5 kph)] from the upstream to the downstream location, regardless of whether drone radar was off or on. Passenger vehicle speeds, which averaged 6 to 8 mph (10 to 13 kph) above the speed limit, were in all cases higher than the mean speed of trucks. The differences were significant at the drone and downstream stations at Site 11 and at the downstream station at Site 12. With radar on, mean passenger vehicle speeds were only slightly lower than with radar off at all but one station, where the mean speeds were the same. Mean truck speeds were 1.0 to 2.0 mph (1.6 to 3.2 kph) lower at all locations with radar on. However, the effect of radar was associated with significantly different speeds for all vehicles only at Site 11 (Figure 8).

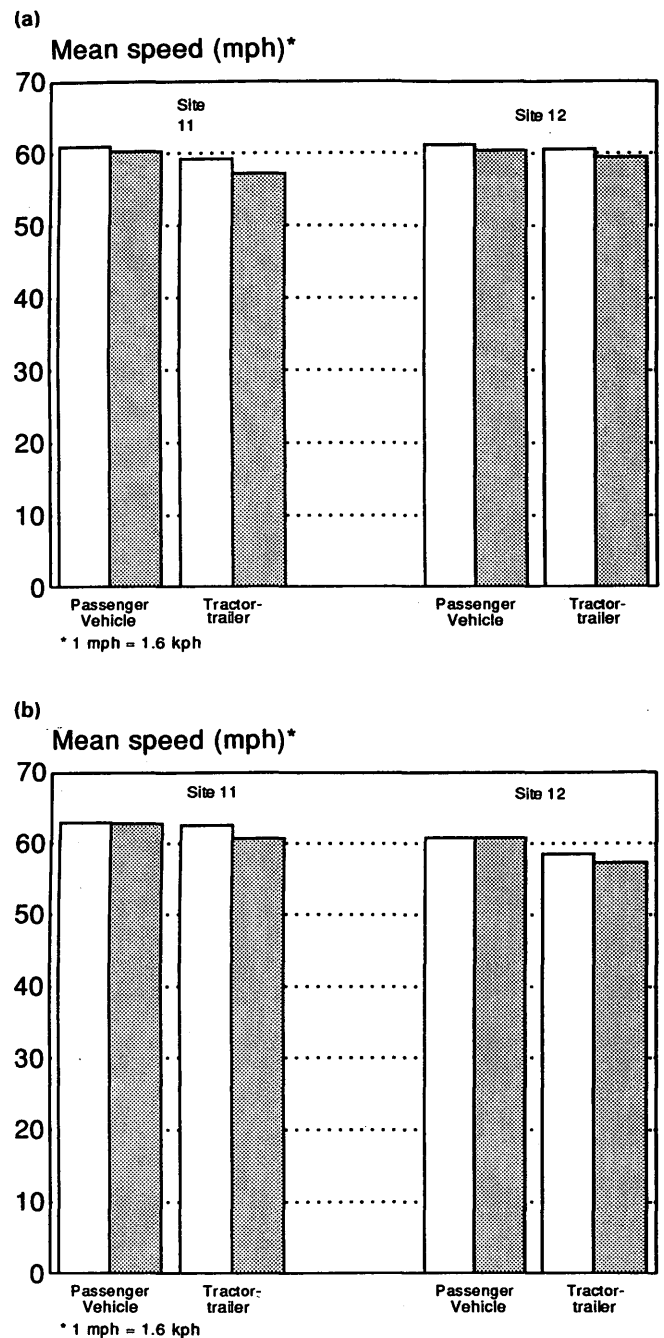
At drone locations, the proportion of passenger vehicles traveling more than 10 mph (16 kph) over the speed limit was lower with radar on, but was significantly lower only at Site 12, as shown in Figure 9. Conversely, the proportion of high-speed passenger vehicles was slightly but not significantly higher with radar on at downstream locations. High-speed tractor-trailers were in most cases less evident with radar on, but the differences were not significant.

## DISCUSSION OF RESULTS

The results of this study indicate that the operation of drone radar can somewhat reduce the speeds of passenger vehicles (cars, pickups, utility vehicles, and vans) and tractor-trailer combinations at many long- and short-term construction and maintenance work zones and high crash locations on urban and rural freeways. These effects on speed were generally evident at the specific locations where a speed reduction was deemed necessary and were also found to exist at least 0.2 to 0.8 mi (0.3 to 1.3 km) downstream at long-term construction zones and 0.2 to 0.5 mi (0.3 to 0.8 km) downstream at temporary work zones. At urban and rural high crash locations, speeds generally remained lower for at least 0.4 to 0.8 mi (0.6 to 1.3 km) downstream when radar drones were activated. However, mean speeds were far above the speed limit, even when the drone radar was operating.

Tractor-trailer mean speeds were generally reduced much more than speeds of passenger vehicles, but this was not always the case and was statistically significant at only two sites. The greater influence on truck speeds is likely because of the more frequent use of radar detectors among heavy trucks. Radar detectors are used in about 4 to 7 percent of cars and light trucks and in 30 to 69 percent of tractor-trailers (9-11). It is therefore likely that a much larger proportion of tractor-trailers would slow near drone radar, influencing the mean speeds of those vehicles by a greater amount.

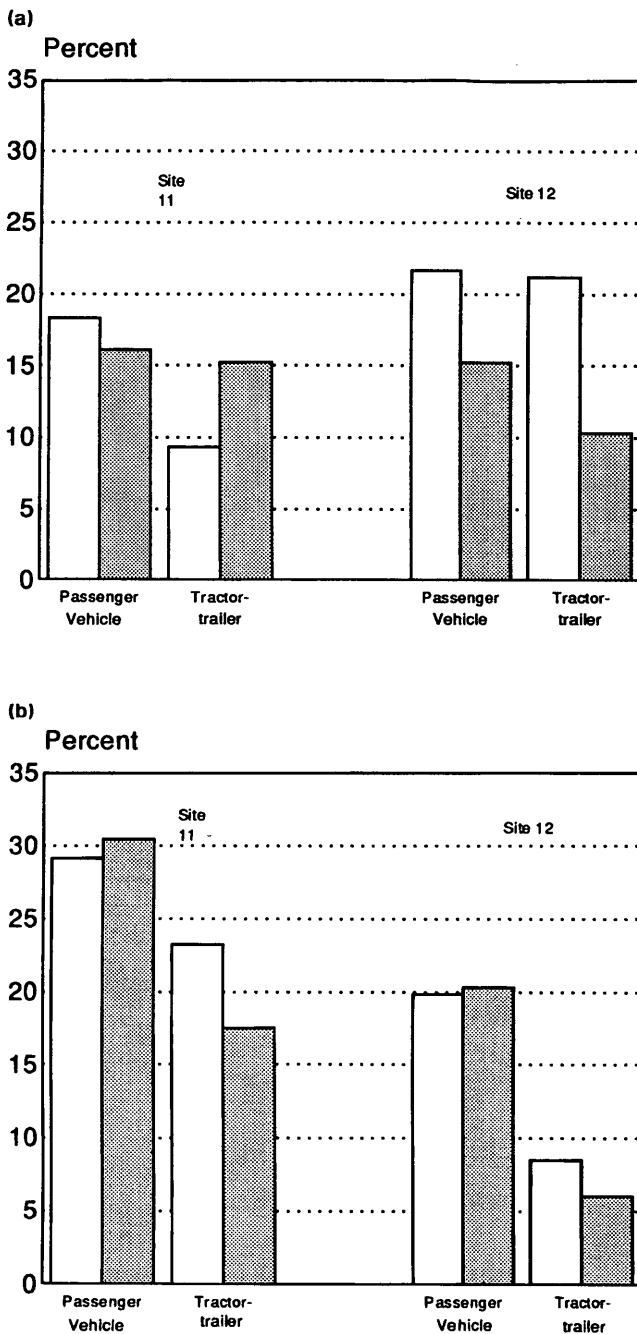
The magnitude of the reductions in mean speed were found to be moderate, at most. Passenger vehicle mean speeds were reduced by no more than 3.4 mph (5.5 kph) at work zones and by a maximum of 1.8 mph (2.9 kph) at high crash locations, but they were found to increase up to 0.8 mph (1.3 kph) at Sites 6 and 9. Tractor-trailer speeds were reduced by up to 3.6 mph (5.8 kph) at work zones and 2.0 mph (3.2 kph) at high crash locations, but they increased at just one measurement station (Site 6, downstream). However, moderate reductions in mean speed were associated with more meaningful reductions in the proportion of vehicles exceeding the speed limit, especially among the fastest vehicles. Radar detector use has been found to be associated with higher travel speeds (9,10). Consequently, drone radar is likely to affect fastest vehicles more, slowing them more than vehicles traveling at slower speeds. In the present



**FIGURE 8** Mean speeds for passenger vehicles and tractor-trailers at urban Interstate high crash sites: (a) drone location and (b) downstream location (shaded bar, radar on; white bar, radar off).

study, proportions of excessive speeders were often (significantly) reduced by one-third to one-half when radar drones were on.

In most locations, especially construction and maintenance work zones, speeds decreased as vehicles went from upstream to downstream stations and speeds were lower with radar on than with radar off. However, at Site 9, a rural high crash location, and at Site 6, an urban short-term work zone, tractor-trailer speeds increased from upstream to downstream and were higher at the downstream loca-



**FIGURE 9** Percentage over speed limit by more than 10 mph (16 kph) for passenger vehicles and tractor-trailers at urban Interstate high crash sites: (a) drone location and (b) downstream location (shaded bar, radar on; white bar, radar off).

tion when the drone radar was on. The speed difference at the downstream station was significant at Site 6. It is possible that this unexpected outcome may have been because the radar drone was observed and reported over two-way citizen-band radios by truck drivers, who then accelerated as they left the study areas. If this undesirable behavior was because drivers realized that the radar signal was produced by a drone device, then more care must be taken to camouflage the drone radar units and active enforcement must be periodically used to heighten the credibility of the radar signal.

The unusual pattern of increasing speed from the upstream to the downstream stations at Site 11, an urban high crash location, could have been caused by normal traffic behavior in that area or an upstream disturbance in traffic flow. Such a disturbance could have slowed vehicles at first, then permitted them to accelerate downstream from it. Even in such a situation, the use of drone radar was associated with significantly lower speeds, especially among tractor-trailers.

Agencies that consider using unattended radar to reduce speeds at hazardous roadway locations should be aware of the FCC regulations prohibiting the use of unattended radar that does not use the return signal in some way, such as triggering a light, counter, or speed warning device. An effect of this restriction, however, is that drone radar units are more expensive than they need to be for their intended purpose, which will likely limit their use.

#### ACKNOWLEDGMENTS

This study was made possible by many organizations and individuals dedicated to improving highway safety. The Shelter Insurance Group, through Mike McMillen, initiated the project by bringing participants together. C.M. Fisher of the Missouri State Highway Patrol brought together necessary public agencies and provided highway crash data. Larry Baucom coordinated the research team with local highway patrol offices. The study would not have been possible without Joe Mickes of the Missouri State Highway and Transportation Department, John Ostrander, the project coordinator, and the engineers and maintenance supervisors at Districts 4 and 5. The work was supported by the Insurance Institute for Highway Safety. Sharon Rasmussen and Lynn Duley, who prepared this manuscript, are also greatly appreciated.

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*Publication of this paper sponsored by Committee on Traffic Law Enforcement.*