Evaluation of Unmanned Radar Installations

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Several unmanned radar devices were installed on Interstate 75 in northern Kentucky in an attempt to reduce speeds. It was assumed that drivers use radar detectors to exceed the speed limit thus causing a variance between their speeds and those of others in the traffic stream. Since historical data indicated an unusually high accident rate for the study area, a reduction in overall speeds and variance was expected to reduce the probability of accidents. The high accident rate also resulted in a plan to reduce trucks on I-75 in the study area by diverting them onto a bypass route (I-275). Emphasis was placed on collection and analysis of speed-related data. In addition, a survey of radar detector use was made and accident patterns were documented. Speed measures analyzed included mean speed, standard deviation in speed, numbers of vehicles exceeding specified speed levels, and 85th percentile speed. Results indicate that unmanned radar was an effective means of reducing the number of vehicles traveling at excessive speeds. The differences in mean speeds were small and the impact of unmanned radar was less obvious than it was for the percentage of vehicles exceeding speed levels of 65, 70, 75, and 80 mph. The speeds of vehicles with radar detectors decreased significantly as a result of unmanned radar, whereas the speeds of vehicles without detectors were not affected. Radar detector use was found to be 42 percent in trucks and 11 percent in cars. When comparing accident data 3 years before and 1 year after truck diversion and unmanned radar installations, there was a reduction in truck-related and speed-related accidents.

In an attempt to improve safety by reducing speeds on Interstate 75 (I-75) in northern Kentucky, five unmanned radar units were installed in the summer of 1986. These units remained on for approximately 3 months and were then turned off after the Federal Communications Commission ruled that unmanned radar transmitters were in violation of their regulations. In the fall of 1986, legislation was passed by Congress that exempted a short section of I-75 in northern Kentucky from Federal Communications Commission requirements (*1*). This legislation mandated that a demonstration project be conducted to assess the benefits of continuous use of unmanned radar equipment. After the legislation was signed by the President on October 27, 1986, plans were made for conducting the demonstration project. As a result of a meeting in Frankfort, Kentucky, on December 21, 1986, between representatives of the Kentucky Transportation Cabinet, FHWA, and the Federal Communications Commission, the units were turned on again.

Preliminary plans were made for an evaluation study to be performed by the University of Kentucky's Transportation Research Program, in cooperation with the Kentucky Department of Highways and FHWA. Additional radar units were installed in the spring of 1987, with all except one unit operational by June 11, 1987. The last unit to be installed began operating in early August 1987. The study area was divided into two sections of radar signal coverage as shown in Figure 1. The full coverage area included nine radar units and extended from Milepoint (MP) 187.2 at 0.5 mi south of the Ft. Mitchell interchange to Milepoint 191.2 at the Ohio River. The partial coverage area included six units and extended from Milepoint 178.2 (about 1 mi south of Florence) to Milepoint 187.2. In the partial coverage area, the radar units were spaced intermittently; however, there were approximately equal distances (4.5 mi) from which the radar signal could and could not be received with a radar detector. The radar units were installed for northbound traffic; however, the signal also could be received by southbound traffic. Throughout the period from the first unmanned radar installations until the study was completed, significant media attention was given to the project. This attention created some problems with respect to vandalism; however, the overall data collection effort was not adversely affected.

STUDY AREA CHARACTERISTICS

The section of I-75 in northern Kentucky covering a length of approximately 4 mi from Ft. Mitchell to the Ohio River has been noted for its exception to the general interstate guidelines for grade and curvature. Most of I-75 in the study area was constructed in the early 1960s, and the problems associated with excessive grade and curvature in an urban area have been documented since. Parts of the study area have grades of 5 percent (downgrade for northbound traffic) and curves of 6 degrees. In 1971, a congressional subcommittee held a public hearing in Covington, Ky., to discuss the hazardous nature of that section of I-75. Soon afterwards, the Department of Highways' Division of Research conducted an evaluation of various safety features that had been installed on that section of I-75, and the results indicated a reduction in accidents (*2*). Other improvements have been made over the years, but the positive impact of improved safety generally has been offset by an increased volume of traffic and resulting congestion. Another recent change in an attempt to improve safety was the diversion of through trucks onto the I-275 circle route around Cincinnati, Ohio (started on July 8, 1986).

The section between Ft. Mitchell and the Ohio River has six lanes of through traffic and carries the highest volumes of any roadway in Kentucky. Average daily volumes for this

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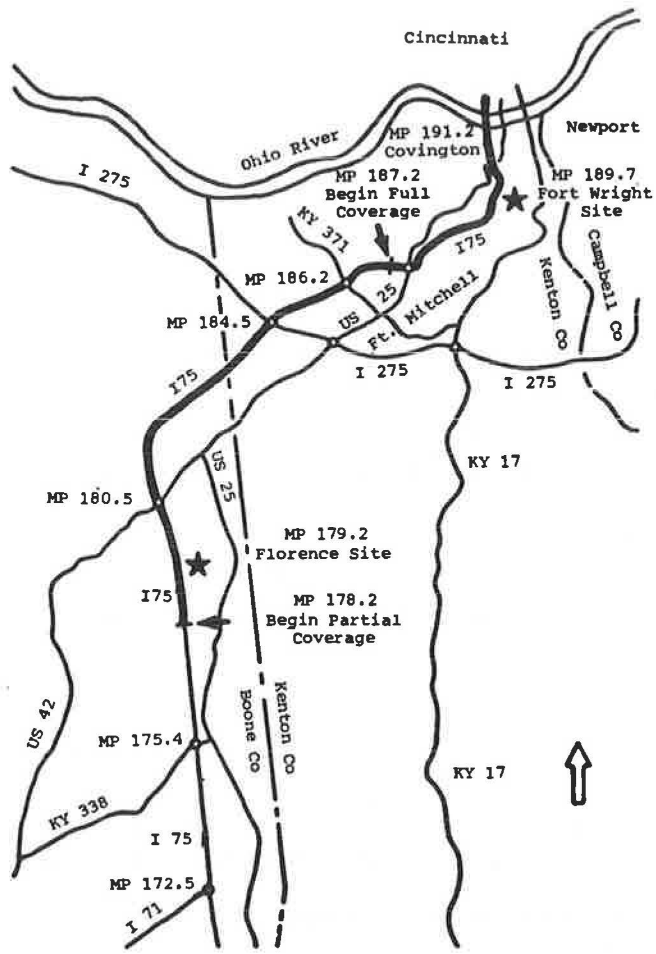

FIGURE 1 Map showing significant points in study area.

section are in the range of 120,000 vehicles. This compares to an annual average daily traffic (AADT) volume of about 60,000 at Florence, which is approximately 10 mi south. For northbound traffic, the percentage of trucks ranged from approximately 26 percent just south of the I-275 interchange to 9 percent in Covington.

The speed limit on I-75 is 55 mph in the southern part of the study area and changes to 50 mph for cars at Milepoint 188.0, 0.3 mi north of the Ft. Mitchell (U.S. Route 25) interchange (Figure 1). In the area of a 50-mph speed limit for cars, the limit for trucks is 45 mph. The breakpoint for change from the 65-mph speed limit (effective June 8, 1987, for rural interstates in Kentucky) to 55 mph is at the KY 338 interchange (MP 175.4), just south of the study area.

RELATIONSHIP BETWEEN SPEED AND SAFETY

Speed has been determined to be one of the most common contributing factors in vehicular accidents. In Kentucky, speed is listed as a contributing factor in 8.9 percent of all accidents and 36.7 percent (the most frequently cited factor) of fatal accidents (*3*). Consideration of speed presents a dilemma in highway transportation because it affects both safety and efficiency. The basic relationship between speed and stopping distance indicates that stopping distance increases in relation to the square of the speed, and the result can be a higher accident potential. Conversely, increased speed can reduce travel costs and increase the operating efficiency of a highway.

The relationship between speed variance and safety has been investigated, and it has been shown that the greater the variation in speeds, the higher the probability of an accident, assuming equal exposure (*4,5*). Another study examined speed variance, and it was found that both slow drivers and fast drivers had accident rates that were approximately six times that of drivers operating close to the mean traffic speed (*6*).

It also has been documented that the greater the absolute speed, the greater the likelihood of increased accident severity (*7*). The energy dissipated during a collision is directly proportional to the vehicle's weight and to the square of its speed. Therefore, increased speed results in more energy dissipation, which translates into greater damage to the vehicle and more injuries to the occupants.

The question of whether the use of radar detectors results in increased accidents remains unanswered. Insufficient research has been conducted to address the issues that are necessary for proper evaluation. Those issues include (a) socioeconomic characteristics of drivers using radar detectors as compared with those of the normal driving population, (b) accident rates based on exposure by type of highway, and (c) overall safety and handling characteristics of vehicles in which radar detectors are used.

EFFECT OF ENFORCEMENT ON SPEED

The presence of police enforcement has been shown to have the effect of decreasing speeds (*8,9*). The use of speed enforcement, a speed-check zone, or a parked patrol vehicle produced significant reductions in speeds in the vicinity of the enforcement unit in another study (*10*). Increased police enforcement in work zones has produced positive effects in terms of speed reduction (*11*). Active police enforcement in conjunction with the use of radar units has been used in many situations to reduce speed.

DATA COLLECTION

Several types of data were collected in an attempt to evaluate the impact of unmanned radar installations on speed. In addition to speed-related data, a survey of radar detector use was made and historical accident patterns were documented.

Automatic Speed Data

Speed data were collected by using automated equipment connected to loops embedded in the roadway at two locations. The speed monitoring station at Ft. Wright (MP 189.7), installed specifically to collect data for this study, became operational on July 6, 1987. Data were collected for approximately 70 days, with some gaps, through November 1, 1987. During the period of data collection, each of the three northbound lanes of I-75 were monitored separately and data for a sample of 2,180,512 vehicles were collected with radar on and for 1,576,615 vehicles with radar off.

The second speed monitoring station was located at Florence (MP 179.2), approximately 10.5 mi south of the Ft. Wright location. This site is among those included in the 55 mph Compliance Speed Monitoring Program of the Kentucky Department of Highways. Data collection was limited to an 18-day period in October and the sample size was 236,471 vehicles with radar on and 266,267 vehicles with radar off.

Manual Speed Data

Manual speed data were collected to supplement the automatic data so that speed data could be collected at additional points in the study area. Data were collected by using time-distance methods (stopwatch measurements over a preselected distance) rather than by radar to ensure that radar signals would not be present in the radar-off condition. Data were collected by three observers at four locations in the study area between June 11, and August 27, 1987. A sample of 150 vehicles was collected for each of the three lanes on each of 15 days. Some efforts were made to monitor citizens band radio transmissions to determine the extent of changes in driving behavior by making observations during the manual data collection effort.

The sample size of 150 vehicles in each of the three lanes of travel was sufficient to ensure, at the 95 percent confidence level, that estimates for the mean speed were statistically reliable within ± 1.0 mph. The procedures for determining sample size were obtained from the publication titled *Manual of Traffic Engineering Studies*, published by the Institute of Transportation Engineers (*12*).

Speed Data With and Without Radar Detectors

A determination was made that, in addition to automatic and manual speed data, it would be desirable to determine the speeds of individual vehicles and also be able to note the presence of radar detectors in those vehicles. This type of data was collected at the Ft. Wright speed monitoring location with the speed-classifier unit used to determine speed and the presence of radar detectors determined by visual inspection. Inherent problems with visual inspections were recognized; however, it was felt that a high percentage of detectors on the dash or windshield of a vehicle were noted. Vehicles with detectors mounted in the grille area obviously could not be seen. An observer was stationed on the side of the road at the speed-classifier unit so that speeds of vehicles could be noted the same time that detectors were observed. Data were collected on 14 days between September 1 and November 19, 1987. Total samples were 1,223 with radar off and 2,074 with radar on.

Speed Data With and Without Police Enforcement

In an attempt to assess the impact of police enforcement on speeds in the study area, additional data were collected with radar on and radar off in the vicinity of the Ft. Wright speed monitoring station. The Kentucky State Police cooperated in this effort, and data were collected on October 21 with radar on and October 28 with radar off. There were three hours of active enforcement on each day.

Radar Detector Data

Samples of data were collected throughout the study period to determine the percentages of vehicles in the I-75 corridor with visible radar detectors. The samples of cars were collected manually by observers as they were traveling on I-75 from Lexington to northern Kentucky. Visual observations were made as they passed or were passed by other vehicles. It also was recognized that some vehicles have built-in detectors that are not visible to observers positioned in another vehicle. Approximately half of the data for cars were collected without distinguishing whether they had in-state or out-of-state licenses. In the second part of the data collection, a distinction was made.

Additional radar detector data were collected by the Kentucky Transportation Cabinet's Division of Motor Vehicle Enforcement. These data were collected as part of vehicle-driver safety inspections (at the truck weight station on I-75 in Scott County), during which truck cab interiors were checked and the presence of radar detectors was noted.

Accident Data

Accident data were obtained from the Department of Highways' Division of Traffic and analyzed for the period between July 1, 1983 and June 30, 1987. This period included 3 years before the initial radar installations in the summer of 1986 and 1 year during which radar was on part of the time and trucks were being rerouted. The accident data were collected for two sections of I-75 as shown in Figure 1—one section representing the area between MP 175.4 (the KY 338 interchange) and MP 187.7 (the Ft. Wright interchange) and the other for the section between MP 187.7 and MP 191.7 (the Ohio River bridge). These sections represent contrasting conditions in terms of geometrics and volume levels. The section between MP 175.4 and MP 187.7 is relatively straight and level with AADTs in the range of 50,000 to 60,000. By contrast, the section starting at MP 187.7 and continuing to the Ohio River at MP 191.7 is the area of sharp curvature and steep grades with AADTs in excess of 100,000.

ANALYSIS OF DATA

Automatic Speed Data

Highway safety researchers generally agree that the safest traffic conditions include those in which vehicles travel at uniform speeds and those in which excessive speeding is minimized. Since any likely impact of radar on safety stems from its effect on speed, measures of primary interest to this study included those that measure both lack of uniformity—i.e., speed variability—and those that measure excessive speeding—i.e., the fractions of vehicles in the traffic stream exceeding stipulated speeds. Speed levels chosen for analysis herein included several at the high end of the speed spectrum, namely, 65, 70, 75, and 80 mph. Other speed measures chosen for analysis included the mean speed and the 85th percentile speed, two measures often examined by traffic engineers in speed studies. The statistical procedure used to analyze these data depended on the speed measure of interest as well as how other factors affecting these speed measures were treated.

The major hypothesis under examination herein is that radar signals can beneficially affect these speed measures, reducing both variability and level of speeds. To test this hypothesis, speed measurements were taken on I-75 during both radar-on and radar-off conditions. Unfortunately, simple differences between these two conditions may be quite misleading: many factors affect speeds and it is imperative to ensure that the analysis is conducted to isolate the effects of radar from those of such other factors.

Factors potentially affecting speed that were controlled in the collection of the automatic data included radar (on or off), day of week (weekday or weekend), light condition (daylight or darkness), and lane of travel (median, center, or shoulder). Unfortunately, other variables possibly affecting speed, such as amount of truck traffic and amount of precipitation, could be neither measured nor controlled. Since data were collected over a sufficiently long interval, the potential confounding effects of these other variables was considered to be small enough to be treated as part of measurement error. An effect not thought to be minimal, however, is that due to volume. That speeds are reduced by the congestion of increased volume levels is an established fact. Since it cannot be controlled in the sense that the above factors can be controlled, volume is treated as a covariate in the analysis of mean speeds and variability of speeds described below.

For the mean speed, the analysis considers the experiment to be a 2^3 factorial (factors: radar, day, and light) with repeated measures (the three lanes of traffic) each with a separate covariate (volume of vehicles in a given lane). The unit of analysis was the mean speed for 1 hour of observation. Evaluation of such an experiment requires an analysis of covariance procedure for a split plot experiment with a covariate for each unit in the split plot (lanes). Because of the size of the data base and the number of factors and their levels, separate analyses were performed for each lane of travel.

Variance of vehicle speeds, a second speed measure computed for each hour of observation, is not normally amenable for investigation by using analysis of covariance techniques because variances are distributed as chi-squared variates and not normal variates. However, for large sample sizes, the chi-squared distribution is well approximated by the normal distribution. Because speeds were measured for a large number of vehicles during each hour of data collection, it was assumed that variance could be treated as a normal variate and that standard analysis of covariance routines could be used for analyzing variance of speed as well as for its mean.

Excessive speeding was measured by the proportions or numbers of vehicles exceeding certain high speed levels. At very high levels, use of the standard analysis of covariance technique becomes suspect because of the small numbers of vehicles involved. An alternate statistical procedure, attributed to Campbell (*13*), is available, however, and is not constrained by the small numbers or proportions of affected vehicles. This procedure, adopted for the analysis herein, treats traffic volume not as a covariate but as a factor similar to day of the week and lane of travel. Although effects of radar can be accurately assessed, the Campbell procedure does not allow analysis of the statistical significance of interactions among the experimental factors.

Manual Speed Data

Data collected with radar on and radar off were separated, and all data for each condition were combined. Using the combined data, the average speed and standard deviation were calculated as well as the percentage of vehicles exceeding 55, 60, 65, and 70 mph. The *t*-test was used to test the statistical significance of the differences in the mean speeds and the *F*-test was used to test differences in standard deviations (*14*).

Speed Data With and Without Radar Detectors

Speeds of vehicles with and without radar detectors were summarized as a function of whether the radar was on or off. For each set of data, the average speed and standard deviation were calculated as well as the percentages of vehicles exceeding 60, 65, 70, and 75 mph. An analysis of variance procedure, with appropriate contrasts, was used to compare mean speeds between the four conditions formed by the combinations of the factors of radar on and off and cars with and without detectors. Bartlett's procedure was used to compare the variability of speeds between these four conditions, and a contingency table analysis was used to compare the proportion of vehicles exceeding 60, 65, 70, and 75 mph between these four conditions.

Speed Data With and Without Police Enforcement

The data used for evaluating the impact of police enforcement on speeds with radar on and radar off consisted of 3 hours of data during each of the conditions. Time periods for data collection were limited because of the availability of enforcement personnel; however, the total sample of vehicles included in each 3-hour period was approximately 8,000. These data were combined into four sets representing (a) active enforcement—radar off, (b) no enforcement—radar off, (c) active enforcement—radar on, and (d) no enforcement—radar on. The combined sets of data were compared statistically by calculating the mean speed, standard deviation, and percentages of vehicles exceeding 65, 70, 75, and 80 mph. The *t*-test was used to test for statistical differences in mean speeds and the chi-squared test was used to determine if differences in the number of vehicles exceeding the speed levels of 65, 70, 75, and 80 mph were different (*13*).

Accident Data

The data were summarized into two location categories and two time categories. The location categories were (a) from the KY 338 interchange to the Ft. Mitchell (U.S. Route 25) interchange and (b) from the Ft. Mitchell interchange to the Ohio River. The time periods were the 3-year period from July 1, 1983 to June 30, 1986, before the start of the unmanned radar and the truck diversion and the 1-year period of July

1, 1986, through June 30, 1987. For each category, the total number of accidents per year and the accident rate were calculated along with the percentages of accidents involving trucks, injuries or fatalities, speed as a contributing factor, darkness, and a wet or snowy pavement.

RESULTS

Automatic Speed Data

A comparison of the mean speeds at the Ft. Wright and Florence speed monitoring stations is presented in Table 1. Specifically, Table 1 gives the mean speeds at each station with radar on and with radar off for each lane of traffic under all other conditions by type of day (weekday and weekend) and by type of light (daylight and darkness). Mean speeds were computed by first regressing average speed on traffic volume for each hour of study via an analysis of covariance and then computing the predicted mean speed at the average level of traffic volume in the resulting regression equation. These adjusted mean speeds were next compared by using the analysis of covariance, and the corresponding *P* values.

At the Ft. Wright station, the adjusted mean speeds for both the median and center lanes with radar on were lower than the corresponding adjusted mean speeds with radar off for each type of condition listed above. None of these differences was determined to be statistically significant. Although the adjusted mean speeds were not consistently lower in the shoulder lane when radar was on, there was no statistically significant difference between adjusted mean speeds when radar-off and radar-on speeds were compared for this lane.

At the Florence station the use of the unmanned radar installation produced significantly lower mean speeds with radar on when compared with radar-off speeds for all three lanes of traffic. According to Table 1, the effect of radar varied by the day of week, with radar producing a larger reduction in speeds on weekends for all three lanes. The effect of radar also varied with the type of light, with radar producing a larger reduction in speeds at night for both center and shoulder lanes.

Adjusted mean speeds at the Florence station were higher than at the Ft. Wright station, which was expected because of the lower speed limit, higher traffic volumes, and restricted roadway geometrics at the Ft. Wright station. The speed limit at Florence was 55 mph compared with 50 mph for cars and 45 mph for trucks at Ft. Wright. AADTs at Florence were in the range of 50,000 to 60,000 compared with 100,000 to 120,000 at Ft. Wright. In addition, roadway geometrics at Florence were generally straight and level compared with relatively sharp curves and steep grades at Ft. Wright.

A comparison of the actual and expected number of vehicles traveling above various speeds is shown in Table 2. The actual number of vehicles was the number of vehicles traveling above the given speed with radar on. This number was compared with an expected number of vehicles traveling above a given speed, which was calculated by using the data obtained with radar off. Essentially, data collected under radar-off conditions were adjusted so that the proportion of total observations occurring within each elemental analysis unit was identical to that occurring under radar-on conditions. Each speed measure, so adjusted, is considered to be the expected value in the absence of radar: it is compared with the actual value measured with radar on to identify the most likely effects of the radar.

The data in Table 2 show what was found to be a statistically significant decrease in vehicles traveling above the high speeds of 65 to 80 mph at both locations. This decrease was greater at Florence than at Ft. Wright, which is logical since the speeds at the Florence station were higher. The traffic volume at the Florence station was about one-half that at Ft. Wright. The high traffic volume combined with the restrictive roadway geometrics at Ft. Wright could result in a greater safety benefit from the reduction in excessive speeding than at Florence, even though fewer vehicles were affected. Daily reductions in the number of vehicles exceeding the various speeds are listed. The reductions per day vary from 2,199 exceeding 65 mph at the Florence station to 6 exceeding 80 mph at Ft. Wright.

A comparison of the actual and expected number of vehicles traveling above various speeds was made as a function of lane. The reductions in speed were generally highest in the median lane at Florence, whereas the reductions were generally highest for the shoulder lane at Ft. Wright. There were reductions in each lane at both locations, with all the differences determined to be statistically significant.

The differences in actual and expected number of vehicles traveling above various speeds, as a function of the day of

TABLE 1 ADJUSTED MEAN SPEEDS FROM ANALYSIS OF COVARIANCE

		Median Lane		Center Lane		Shoulder Lane	
Variable	Category	Radar On	Radar Off	Radar On	Radar Off	Radar On	Radar Off
Florence							
All	All	64.50	66.36	62.06	63.72	57.15	58.61
Day of week	Weekday	65.07	66.45	62.52	63.79	57.41	58.58
	Weekend	63.93	66.28	61.60	63.65	56.90	58.64
Light	Daylight	65.42	67.27	63.11	64.45	57.75	58.88
	Darkness	63.58	65.46	61.01	62.99	56.56	58.34
Ft. Wright							
All	All	62.82	62.98	57.85	57.88	54.57	54.46
Day of week	Weekday	62.74	62.91	57.71	57.77	53.58	53.52
	Weekend	62.89	63.05	57.99	58.00	55.56	55.40
Light	Daylight	64.26	64.40	59.01	59.11	55.65	55.48
	Darkness	61.38	61.56	56.69	56.66	53.48	53.44

NOTE: Mean speeds are adjusted to the average level of traffic volume in the lane.

the week, were analyzed. There was a larger reduction in excessive speeds on the weekend at Florence than on weekdays; no such difference was detected at Ft. Wright. All reductions were statistically significant.

The differences in actual and expected number of vehicles traveling above various speeds, as a function of light condition, were also analyzed. At Florence, the reductions during darkness were slightly higher than those during daylight. There were no substantial differences between daylight and darkness at Ft. Wright. All of the differences were statistically significant.

Comparisons were made of actual and expected numbers of vehicles above various speeds as a function of traffic volume. There were reductions in every category, and almost all were statistically significant; however, no trend was detected in which the reductions could be related to traffic volume.

A comparison of the variation of speeds at the two stations is presented in Table 3. This table includes the adjusted standard deviations of speeds at each station with radar on and with radar off for each lane of traffic and for various combinations of radar with the type of day and type of light. At the Ft. Wright station the adjusted standard deviation of speeds with radar on (4.97) in the median lane is significantly lower than the corresponding standard deviation with radar off (5.08); the standard deviation with radar on (4.66) in the center lane is significantly lower than the corresponding standard deviation with radar off (4.79). For the shoulder lane the adjusted standard deviation with radar on is significantly lower than the standard deviation with radar off for weekdays but not weekends or for daylight but not darkness. For both the center and shoulder lanes the adjusted standard deviation of speeds was significantly higher on weekdays as opposed to weekends and during daylight as opposed to darkness.

At the Florence station, similar results were obtained for the effect of radar in that the adjusted standard deviation of speeds was significantly lower when radar was on compared with when radar was off for both the center and shoulder lanes. For the median lane there was a significant radar-by-light interaction. The effect of light is different at the Florence station, with darkness producing more variable speeds for the median lane, fewer variable speeds for the shoulder lane, and no significant effect for the center lane.

The 85th-percentile speed is a measure commonly used to describe variation in traffic speeds. A summary of the actual and expected 85th percentile speeds at the Ft. Wright and Florence stations for the various categories is presented in Table 4. The actual speeds with radar on were lower than the expected speeds, using the radar-off data, for every category. The differences, although small, were larger than those found

TABLE 2 RADAR EFFECTS ON NUMBER OF VEHICLES ABOVE VARIOUS SPEEDS

		No. Over Speed		Percent Over Speed		Percent Reduction	No. Over Speed per Hour[c]		
Location	Speed	Radar On (Actual)[a]	Radar Off (Expected)[b]	Radar On (Actual)	Radar Off (Expected)	Because of Radar	Radar On (Actual)	Radar Off (Expected)	Reduction per Day
Florence	80	751	1,265	0.32	0.53	40.6	3.5	5.0	36
	75	2,336	4,396	0.99	1.86	46.9	11.0	20.8	234
	70	11,954	19,828	5.06	8.38	39.7	56.5	93.7	894
	65	55,631	75,023	23.53	31.73	25.8	262.8	354.5	2,199
Ft. Wright	80	983	1,240	0.05	0.06	20.6	1.0	1.3	6
	75	5,018	6,228	0.23	0.31	25.8	5.2	6.5	31
	70	44,940	50,668	2.07	2.53	18.2	46.8	52.8	144
	65	258,991	273,301	11.90	13.42	11.3	269.7	284.6	358

NOTE: All differences were significant at the 0.05 level.
[a]Actual number of vehicles recorded above given speed with radar on.
[b]Expected number of vehicles above given speed using data obtained with radar off.
[c]Based on number of hours of data obtained with radar on (635 lane-hours at Florence and 2,881 lane-hours at Ft. Wright).

TABLE 3 STANDARD DEVIATION OF SPEED FROM ANALYSIS OF COVARIANCE

		Median Lane		Center Lane		Shoulder Lane	
Variable	Category	Radar On	Radar Off	Radar On	Radar Off	Radar On	Radar Off
Florence							
All	All	5.52	5.82	5.38	5.51	5.41	5.58
Day of week	Weekday	5.57	5.60	5.35	5.47	5.31	5.48
	Weekend	5.48	6.02	5.42	5.55	5.51	5.68
Light	Daylight	5.38	5.36	5.41	5.44	5.55	5.65
	Darkness	5.67	6.24	5.36	5.57	5.28	5.51
Ft. Wright							
All	All	4.97	5.08	4.66	4.79	6.02	6.08
Day of week	Weekday	4.95	5.08	4.71	4.83	6.27	6.39
	Weekend	4.99	5.08	4.61	4.74	5.76	5.76
Light	Daylight	4.82	4.91	4.71	4.80	5.93	6.05
	Darkness	5.12	5.24	4.62	4.77	6.11	6.12

NOTE: Mean variances of speed are adjusted to the average level of traffic volume in the lane. Standard deviations reported above are square roots of the adjusted mean variances.

for the mean speeds at the Ft. Wright station. The differences were larger at Florence than at Ft. Wright and were similar to those found for the mean speeds. No statistical analyses were performed to compare the 85th percentile speeds.

Manual Speed Data

The manual data collected at the four locations were summarized and included average speed, standard deviation, and the percentage of vehicles exceeding various speeds. Statistical tests indicated that none of the differences in average speed was significant. There was no general trend in the speeds with radar on or radar off at two locations. Speeds at one location were lower with radar on. The results show that the sample of speed data collected manually was apparently insufficient to include all the conditions that would identify differences expected by time of day, day of week, light conditions, and traffic volumes.

Speed Data With and Without Radar Detectors

The summary of speed data for vehicles with and without a radar detector is presented in Table 5. The data also are summarized with radar on and radar off. All data were collected in the median lane at the Ft. Wright speed monitoring station. The analysis showed that, when the radar was off, the percentage of vehicles with a speed over specified high speeds was higher for vehicles with radar detectors. Conversely, when the radar was on, the percentage of vehicles with speeds over these high speeds was higher for vehicles without a radar detector. It is also interesting to note the reduction in the percentage of vehicles with detectors traveling above these speeds when the radar was on. For example, the percentage of vehicles exceeding 65 mph was about 36 percent for vehicles with radar detectors during radar-off conditions, and this percentage decreased to about 20 percent during radar on conditions. Conversely, this percentage did not change for vehicles with no radar detector, with 28 percent during radar-off and 27 percent during radar-on conditions.

TABLE 4 RADAR EFFECTS ON 85TH PERCENTILE SPEED

	Ft. Wright		Florence	
Variable	Radar On (Actual)	Radar Off (Expected)	Radar On (Actual)	Radar Off (Expected)
All	65.41	65.55	67.31	68.58
Day of week				
Weekday	64.14	64.28	67.47	68.62
Weekend	64.79	64.93	66.73	68.47
Lane				
Median	67.68	67.88	69.44	71.27
Center	62.21	62.39	67.77	68.91
Shoulder	59.60	59.63	63.01	64.04
Light conditions				
Daylight	64.46	64.61	67.74	68.88
Dark	63.69	63.85	65.81	67.61
Traffic volume (vehicles per hour)				
<300	64.22	64.45	67.82	69.14
300–599	64.44	64.61	66.46	67.93
600–899	64.40	64.50	67.76	68.90
900–1,200	65.39	65.68	68.15	68.91
Over 1,200	63.36	63.48	—[a]	—[a]

[a]There were no data in this traffic volume category.

TABLE 5 RADAR EFFECTS ON SPEEDS OF VEHICLES WITH AND WITHOUT DETECTORS

	Radar Off		Radar On	
	With Detector	No Detector	With Detector	No Detector
Sample size	132	1,091	121	1,953
Average speed (mph)	64.64	63.57	62.60	63.49
Standard deviation	4.64	4.21	3.74	4.02
Percent speeds over 60 mph	81.8	79.9	71.9	80.4
Percent speeds over 65 mph	36.4	27.7	19.8	26.7
Percent speeds over 70 mph	10.6	5.0	4.1	4.1
Percent speeds over 75 mph	2.3	1.0	0.0	0.9

NOTE: All data were taken in the median lane at Ft. Wright speed monitoring station.

A comparison of mean speeds between the four conditions given in Table 5 using a one-way analysis of variance F-test, indicated statistically significant differences in the means. These data show that, although mean speeds decreased significantly for cars with detectors when comparing radar-off and radar-on conditions (64.64 mph compared with 62.60 mph), mean speeds did not change significantly for cars without detectors (63.57 mph compared with 63.49 mph). With radar off, the average speeds of vehicles with detectors were higher than vehicles without detectors (64.64 mph compared with 63.57 mph); conversely, with radar on, the average speeds of vehicles without detectors were higher than vehicles with detectors (63.49 mph compared with 62.60 mph).

The change in the variability of speeds can be shown in the standard deviations. A comparison between the standard deviation of speeds under the four conditions given in Table 5 was made using Bartlett's statistic ($P < 0.05$). The data show that the variability of speeds was decreased significantly under the radar-on condition for vehicles with radar detectors as well as for those without detectors. For vehicles with radar detectors, the standard deviation decreased substantially (4.64 compared with 3.74) as a result of radar. When the radar was off the standard deviation of speeds of vehicles with detectors was higher than those without detectors (4.64 compared with 4.21); when the radar was on, the standard deviation of speeds of vehicles without detectors was higher than those with detectors (4.02 compared with 3.74). These data show that the variability of speeds was decreased under the radar-on condition, especially for vehicles with radar detectors.

Speed Data With and Without Police Enforcement

The effect of active enforcement show that both the mean speeds and the percentages of vehicles exceeding various speeds were reduced as a result of active police enforcement. These reductions occurred both with radar on and radar off. The reductions in mean speed and the percentage exceeding 65 mph and 70 mph were determined to be statistically significant. There were greater reductions in mean speeds and percentage of vehicles exceeding 65 and 70 mph for radar-on conditions compared with radar-off conditions. For example, the reduction in percentage of vehicles exceeding 65 mph was 48 percent with and without active enforcement for radar off compared with 65 percent with and without active enforcement for radar on.

Radar Detector Data

A sample of 318 trucks was inspected by the Division of Motor Vehicle Enforcement during its regular inspection activities at the Scott County weigh station on I-75 between May 15 and June 1, 1987. A visual inspection of the truck cab interiors revealed that 135, or 42.4 percent, of the trucks had radar detectors.

Observations of the number of vehicles with visible detectors were conducted on 14 days between June 2 and August 22, 1987, on I-75 during trips between Lexington and northern Kentucky. A sample of 768 cars between June 2 and July 30 showed that 66, or 8.6 percent, had radar detectors. Another sample between August 4 and August 22 classified the cars as in-state and out-of-state vehicles. There was very little difference between in-state and out-of-state cars, with 13.5 percent (55 of 406) in-state cars and 12.9 percent (55 of 426) out-of-state cars having radar detectors. Combining all the data yielded 11.0 percent of cars with detectors.

Accident Analyses

A summary of the analysis of accident records is presented in Table 6. The summary for the 12.3-mi section between the KY 338 interchange and the Ft. Mitchell (U.S. Route 25) interchange was tabulated separately from the 4.1-mi section between the Ft. Mitchell interchange and the Ohio River. The section between KY 338 and Ft. Mitchell had an ADT of about 82,000 over the 4-year study period compared with about 102,000 for the section between Ft. Mitchell and the Ohio River. During the time covered by the radar experiment, there was basically full radar coverage of the section between Ft. Mitchell and the Ohio River and partial coverage for the other section.

The number of accidents and the accident rate were much higher for the section between Ft. Mitchell and the Ohio River. The accident rate for this section during the 3 years before truck diversion and initial radar installations was 245 accidents per 100 million vehicle miles (MVM). This figure was higher than the statewide average of 156 accidents per 100 MVM and a 3-year critical rate of 171 accidents per 100 MVM for urban interstates. Critical rates for various types of highways in Kentucky were determined as part of other research (*3*). The accident rate for the section between the KY 338 and Ft. Mitchell interchanges was much lower (a rate of 42 accidents per 100 MVM during the 3 years before truck diversion and radar installations). Although this section of I-75 is classified as an urban interstate, some parts are more representative of a rural interstate. The average rate for rural interstates is 69 accidents per 100 MVM, and for similar urban interstates the rate is 156 accidents per 100 MVM.

The data were summarized for a 3-year period before July 1986 and a 1-year period after that date. That date coincided with a diversion of northbound trucks from I-75 onto I-275 and also represents the approximate date when the unmanned radar was started. Both of these factors could have the potential for affecting accidents within the northbound lanes in the July 1986 through June 1987 time period. Also, the impact should be most obvious on the section between Ft. Mitchell and the Ohio River since both factors would apply to the total length of this section. However, only a portion of the section between the KY 338 and Ft. Mitchell interchanges would be affected.

A comparison between the two roadway sections and two time periods showed that the major change was on the section between Ft. Mitchell and the Ohio River. Specifically, the accident rate was reduced during the July 1986 to June 1987 time period. This decrease in the number of accidents, primarily in the northbound direction, was shown to be related to a reduction in the number of truck accidents, which was also related to the truck diversion. There was also a reduction in the percentage of speed-related accidents for northbound traffic in this section, which could be related to the unmanned radar.

TABLE 6 ACCIDENT ANALYSIS

	LOCATION			
	KY 338-FT. MITCHELL		FT. MITCHELL-OHIO RIVER	
	7/1/83 - 6/30/86	7/1/86 - 6/30/87	7/1/83- 6/30/86	7/1/86 - 6/30/87
Total Accidents	441	147	1,122	310
Accident/Year				
Total	147	147	374	310
Northbound	82	77	170	121
Southbound	65	70	204	189
Accidents/Mile/Year	120	120	91.2	75.6
Accident Rate(ACC/100 MVM)	42	40	245	204
Percent Truck Accidents				
Total	26.8	23.8	28.9	20.0
Northbound	26.1	23.4	27.6	16.5
Southbound	27.6	24.3	30.3	22.2
Percent Injury or Fatal Accidents				
Total	23.8	25.9	30.7	35.5
Northbound	22.4	23.4	31.2	32.2
Southbound	25.5	28.6	30.5	37.6
Percent Speed Related Accidents				
Total	10.9	6.8	8.0	7.4
Northbound	9.4	9.1	8.0	6.6
Southbound	12.8	4.3	8.1	7.9
Percent During Darkness				
Total	30.6	28.6	33.6	32.3
Northbound	29.0	31.2	26.0	31.4
Southbound	32.7	25.7	40.7	32.8
Percent on Wet or Snowy Pavement				
Total	33.6	22.4	30.6	18.7
Northbound	29.0	23.4	35.2	22.3
Southbound	39.3	21.4	28.5	16.4

SUMMARY AND CONCLUSIONS

The following is a summary of the major findings and conclusions from the analyses performed during this study.

1. At the Ft. Wright speed monitoring station, there was no statistical difference in mean speeds with radar on and radar off.
2. At the Florence speed monitoring station, data indicated that the mean speeds showed a statistically significant decrease with radar on.
3. At both speed monitoring stations, there were statistically significant reductions in the numbers of vehicles exceeding speed levels of 65 to 80 mph when radar-on (actual) and radar-off (expected) speeds were compared.
4. Unmanned radar was demonstrated to be an effective means of reducing the number of high-speed drivers. The reduction per day in numbers of vehicles exceeding the speed limit (55 mph) by 15 mph was determined to be approximately 900 at Florence compared with approximately 350 vehicles per day exceeding the speed limit (50 mph) by 15 mph at Ft. Wright.
5. The variability of speeds at the speed monitoring stations (as measured by the standard deviation) decreased with radar on compared with radar off.
6. The 85th percentile speeds were lower with radar on at the speed monitoring stations. The differences were small at the Ft. Wright station.
7. The manual data collection did not reveal any statistically significant differences when comparing mean speeds with radar-on and radar-off speeds. Results indicated that the sampling periods were apparently insufficient to include all conditions that might identify differences that were shown at locations where automatic equipment was used to collect continuous data.
8. About 42 percent of trucks and 11 percent of cars were observed to have radar detectors. There was no substantial difference in the percentage of in-state and out-of-state cars with radar detectors.
9. Speeds of vehicles with and without detectors for radar-on and radar-off conditions indicated that the use of radar detectors had a significant effect on vehicle speeds. With radar-on conditions, the speeds of vehicles with radar detectors decreased significantly compared with those with radar-off

conditions, whereas the speeds of vehicles without detectors were not affected by the radar. These data also indicated that the variability of speeds was decreased under the radar-on condition, especially for vehicles with radar detectors.

10. Active police enforcement was found to produce a statistically significant reduction in mean speeds and the percentage of vehicles exceeding various speeds for both radar-on and radar-off conditions. However, the effect was more pronounced with radar on.

11. Accidents in the northbound direction on I-75 between Ft. Mitchell and the Ohio River were found to have decreased in the 1-year period after July 1986 compared with the 3-year period before. This reduction was apparently related to the truck diversion and, possibly, the unmanned radar. There was a reduction in the percentage of truck-related and speed-related accidents for northbound traffic in this section.

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