Evaluation of Flagger Training Session on Speed Control in Rural Interstate Construction Zones

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A study was conducted on the evaluation of a flagger training session on speed control in rural Interstate construction zones. Two flaggers were randomly selected to participate in a training session, in which they were taught the *Manual on Uniform Traffic Control Devices* procedures for flagging on rural Interstates. Speeds of traffic outside of the construction zone, inside of the zone but far from the flagger, and inside the zone near the flagger were observed to determine the effectiveness of the flaggers before and after training and to note any increased effectiveness after training. The findings indicate that both cars and trucks have speeds exceeding the speed limit outside the construction zone and far from the flagger, but speeds near the flagger are lower than the speed limit. For both flaggers, the average speeds near the flagger were 4 to 9 mph lower after training than before. For the first flagger, it is not clear whether or not this is a result of an increased effectiveness due to training. However, for the second flagger, it is likely that the reduced speeds are caused by an increased effectiveness after training.

Flaggers are provided to assist moving vehicles and pedestrians safely and efficiently through or around work areas while protecting on-site workers and equipment, either by stopping traffic intermittently or by maintaining continuous traffic past a worksite at reduced speeds to help protect the work crew (*1*). Lack of uniformity in flagging procedures in work zones prompted the question of whether or not contractors' flaggers are flagging according to procedures outlined in the *Manual on Uniform Traffic Control Devices* (MUTCD) (*1*). They may or may not be familiar with the procedure and they may not have learned it through formal training. Training the flaggers to flag according to MUTCD procedures may improve their effectiveness in controlling traffic and increase the safety of workers and motorists. Consequently, a pilot study was performed in which the effectiveness of flaggers in maintaining traffic reducing traffic speeds was evaluated in before and after training conditions. The objectives of evaluating trained flaggers were as follows:

- Determine the effectiveness of the flaggers before training,
- Determine the effectiveness of the flaggers after training, and
- Compare effectiveness in before and after training and suggest possible improvements that may increase the effectiveness of flaggers.

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Previous studies by Richards et al. (*2,3*) reported flagger effectiveness when the flagger was located before the beginning of the taper area. However, because most flaggers are located in the construction zone near the crew, this study evaluated the effectiveness of the flagger when in the zone, rather than in front of the zone. This study considers only the case when the purpose of the flagger is to maintain continuous traffic past the worksite at reduced speeds. Because flaggers are required on this construction project, this study evaluated only the conditions of trained and untrained flaggers, rather than the condition of having no flaggers present. The condition of having no flaggers present would have created substandard construction procedures.

In the study, a contractor was asked to identify and send a few of his regular flaggers to a training session. The contractor identified two male workers who work for him as flaggers. The two flaggers were observed during the study. The flaggers were not told that they were selected to go to the training session until an hour before the session began. The reason that they were not informed about their participation in the program is that they might have performed differently if they knew that they were being trained and that their performance was being monitored.

Flagger effectiveness data were collected for each flagger, both before and after training. The data were collected using a traffic counter and two teams equipped with radars. One measure of effectiveness used to evaluate flaggers' performance was speed of vehicles. Other measures of effectiveness were evaluated (*4*) but because of space limitations, only the evaluation based on vehicle speed is presented.

According to the MUTCD, a flagger should possess the following minimum qualifications: average intelligence, good physical condition, including sight and hearing, mental alertness, courteous but firm manner, neat appearance, and a sense of responsibility for safety of public and crew. The flagger is required to use orange clothing, such as a vest, shirt, or jacket. The flagger must be clearly visible to the approaching traffic for a distance sufficient to permit proper response by speed before entering the worksite. The manual suggests that the flagger stand 200 to 300 ft from the crew. The flagger should stand either on the shoulder adjacent to the traffic being controlled, or in the barricaded lane, and should not stand in the lane being used by moving traffic under any circumstances (*1*).

BACKGROUND

Flagging is used for traffic control and speed reduction in various types of work zones. Because flaggers are responsible for the safety of the crew and drivers, it is important that flaggers be effective in gaining the attention of drivers and reducing the speed of vehicles. Consequently, numerous studies have been made in order to determine the most appropriate manner of increasing the flaggers' effectiveness.

Presently, proper flagging procedures are given in the MUTCD (*1*). However, alternatives to flagging have been considered for study. For example, Ullman et al (*5,6*) investigated alternatives to using flaggers, such as the use of Yield to Oncoming Traffic signs to self-regulate traffic operations, and the use of portable traffic signals. For one-way operations, Bookers et al. (*7*) evaluated the effectiveness of using a reusable temporary stop bar (stop line) and a freestanding oversized Stop/Slow sign paddle to enhance the safety of the flagger.

Several studies have been performed in which variations on the MUTCD flagging procedures were evaluated. Noel et al. (*8,9*) studied the long-term (2 weeks) and short-term (within 3 days) effectiveness of implementing MUTCD flagging and innovative flagging on speed reduction on multilane freeways. Richards et al. (*2,3*) evaluated the immediate effects of MUTCD flagging and innovative flagging on one or both sides of the traveled lane, both of which were supplemented by advisory or regulatory signs.

It is not known if flaggers are following the procedures outlined in the MUTCD. As stated earlier, flaggers may not be familiar with the procedures, or they may not have learned them through formal training. This study is being performed to determine if there is an increased effectiveness of the flagger in slowing down vehicles after the flagger receives proper training on flagging according to MUTCD.

TRAINING SESSION

The training session was conducted by the work zone manager of the Illinois Department of Transportation (IDOT), who had years of experience in training and educating workers on work zone traffic control. The training was conducted outside of the IDOT field office of the construction project site, where the trainer met with the flaggers and informally discussed proper flagging techniques for slowing down vehicles on multilane highways when one lane is closed. The purpose of the training session was to demonstrate the proper use of the Stop/Slow paddle and proper flagging procedures used with this kind of lane closure project. The trainer did not discuss other flagging situations. The flaggers were able to ask questions as they arose. The actual demonstration lasted approximately 15 min. The description of the training session is based on the researchers observations, and does not necessarily reflect the views of the research team.

Key Points of the Training Session

The information taught at the training session was taken from the Illinois Department of Transportation Flaggers' Handbook and was consistent with the flagging techniques described in the MUTCD. The training session reviewed the proper equipment needed, the correct standing position, and the necessary hand gestures needed to slow traffic. Both flaggers were given copies of the Flaggers' Handbook.

Equipment

The flaggers were told that they should wear a high-visibility vest so that they could obtain the attention of the driver. It was suggested that the flagger wear bright orange gloves to help get the driver's attention and make the hand gestures more visible. The trainer recommended using a high-visibility body suit, such as the type that hunters wear, but said that this is not required. The trainer gave a pair of the bright orange gloves to Flagger 2. A standard Stop/Slow paddle should be used to help direct traffic. In Illinois, the minimum required height of the paddle is 6 ft, and the sign should be 24 in. wide.

Position

The flaggers were told that they should stand 200 to 300 ft ahead of the construction crew in the closed lane where they would be visible to the oncoming traffic.

Hand Gesture

The trainer demonstrated the proper hand gestures that should be used when flagging. The Stop/Slow paddle should be held with one hand in an upright position with the Slow sign visible to traffic, and the flagger should use his other hand to direct the traffic. The free hand should be held directly in front of the flagger with the palm outward and continuous sweeping motions downward should be used. When a driver fails to respond to the flagger, the flagger should point to the driver to get his attention and then either use the sweeping motion again or point to the Slow sign.

Comments Made by the Flaggers After the Training Session

After the training session, the flaggers were asked questions pertaining to their perception of the training session. Their comments are given in later sections. Both flaggers felt that what the trainer had told them about flagging techniques was not anything new or unfamiliar to them. Both flaggers thought that it was necessary for them to stand close to the construction crew, rather than stand 200 to 300 ft away from them, because the traffic would move from the shoulder back into the normal driving position in the lane immediately after passing the flagger and would be too close to the crew for safety. When asked what type of treatment would be the most effective in reducing the speeds of traffic, the flaggers replied that police presence with radar would be most effective. They felt that improving flagging techniques was not effective because drivers were already able to tell when the construction crew was present and that they needed to slow down, but that

they were unwilling to do so. The fear of getting a speeding ticket was more effective in slowing down traffic. When asked if they felt any more, the same, or less conscientious about the importance of flagging and the proper techniques to use, they both said that they felt the same amount of conscientiousness about flagging after training as they had felt before the training session.

SITE DESCRIPTION

The study site is located on the northbound lanes of a rural section of Interstate 57 just south of Champaign, Illinois. A typical section of the construction zone is shown in Figure 1. The construction zone, which was approximately 5 mi long, began shortly after the interchange of I-57 and US-45 and ended before the interchange of I-57 and I-72. The terrain in the study site is level, and the roadway does not have sharp curves. Along the construction zone, Interstate 57 is four-lane highway, with two lanes in each direction. However, in each direction, one of the lanes was closed because of the construction work. The flagger treatment was studied on the northbound lane, where the type of construction occurring was joint repair and surface preparation for an asphalt overlay. The speed limit was 65 mph for cars and 55 mph for large trucks, unless specified by speed limit signs with flashing

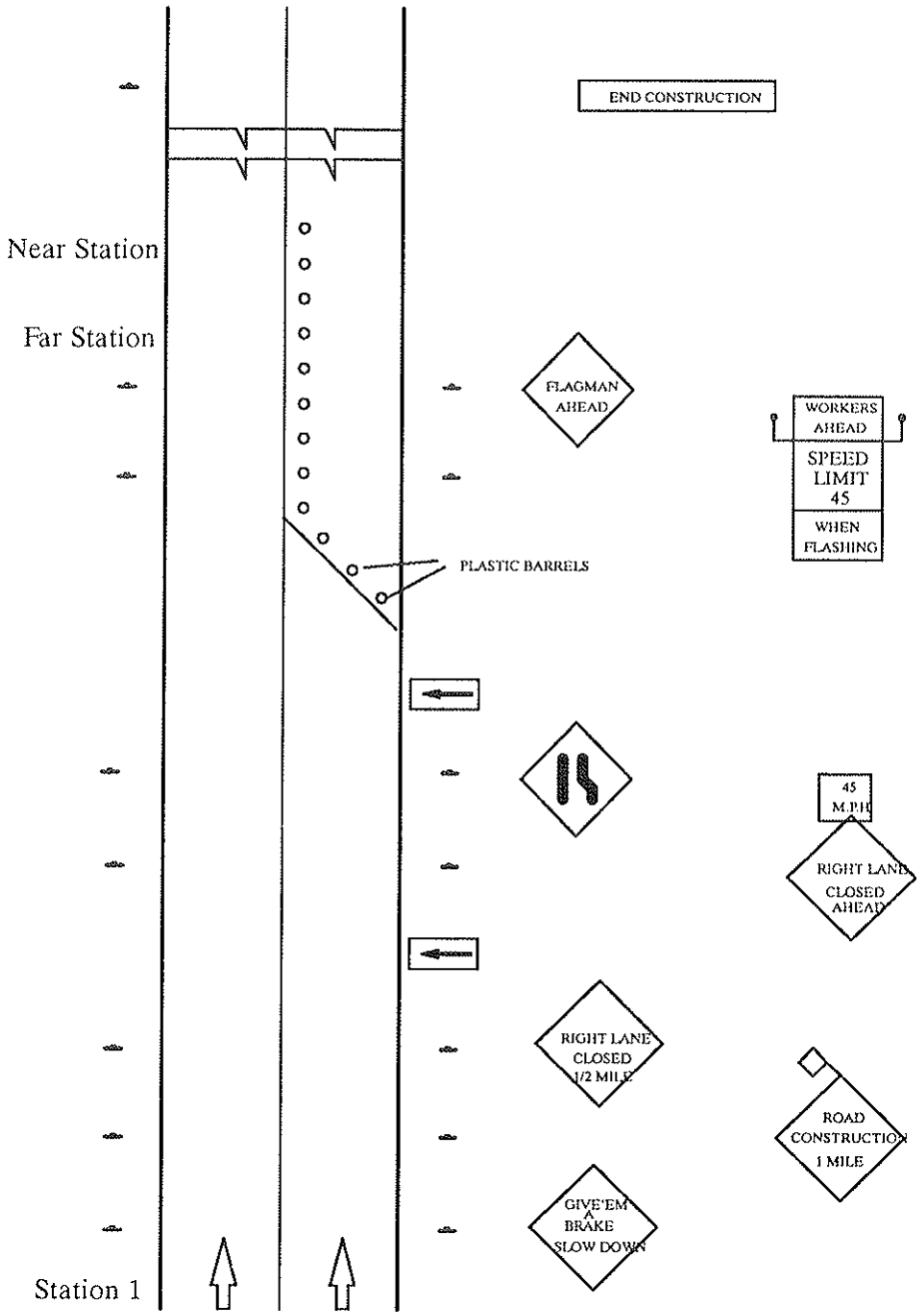


FIGURE 1 Traffic control plan in the construction zone.

lights mounted on them. When the flashing lights were turned on, the speed limit was 45 mph for all vehicles.

The traffic volume in the construction zone was light, being approximately 400 veh/hr. In the average daily traffic (ADT) maps published by the Illinois Department of Transportation, the ADT in the zone is 14,500 veh/day with approximately 17 percent large trucks.

DATA COLLECTION

In order to determine the effectiveness of the flaggers, free flow traffic (not platooned) data were collected at three locations: approximately 1 mi before the construction zone (Station 1), far from the flagger but within the construction zone (far station), and near the flagger (near station). Speed data at Station 1 were collected using a traffic counter and at the far and near stations using radar guns. The speed data at each station are all for the same time period and indicate the speeds for free flow traffic only. Both lanes were open to traffic at Station 1. However, because Station 1 was located upstream of the taper and was not influenced by the construction zone, the inside lane served mostly as a passing lane and was not used heavily. Speeds on the outside lane tended to be lower than those on the inside lane. Consequently, only observations from the outside lane were used as control data, yielding a more conservative analysis. The speeds measured at the far station are a subset of the speeds measured at Station 1, as some vehicles platooned after entering the work zone. By collecting speeds at these points, it was possible to establish a control station and determine how the traffic reacted to the flagger only. Station 1 exhibits travel speeds of vehicles not influenced by the flagger or the construction zone. The far station exhibits travel speeds of vehicles influenced by the construction zone and radar. The near station exhibits travel speeds of vehicles influenced by the construction zone, radar, and the flagger.

All data were collected on weekdays when there were good weather and dry pavement; night conditions and peak traffic periods were avoided. Data were collected either in the early morning or shortly after the lunch break, and at these times, the flaggers did not appear to be tired. Because the flaggers had not been flagging for an extended period of time before data collection, it is assumed that they were not excessively fatigued and that they performed at their usual effectiveness level. During data collection periods, there was no significant change in the layout of the construction zone, the activity taking place, or the type of construction equipment used. Thus, there were not any external factors that influenced the drivers' speeds.

The time, type, color, and speed of vehicles passing each flagger before and after training were recorded by two teams. The speeds of a vehicle where measured near to the flagger, at the near station, and far away from the flagger, at the far station, using two radar guns. The distance between the two stations was about 1,600 to 1,800 ft. A typical data collection setup inside the construction zone is shown in Figure 2. The radar guns had an antidetection bottom that transmitted signals only when it was activated. The radar guns were used because the flaggers did not stay at one location during the entire data collection period. The patching crew worked at one location for approximately half an hour and then moved to the next location that needed repair, with the flagger moving with the crew as well. The radar guns were the most appropriate device for data collection under the moving operations because they could be used anywhere that the flaggers were working.

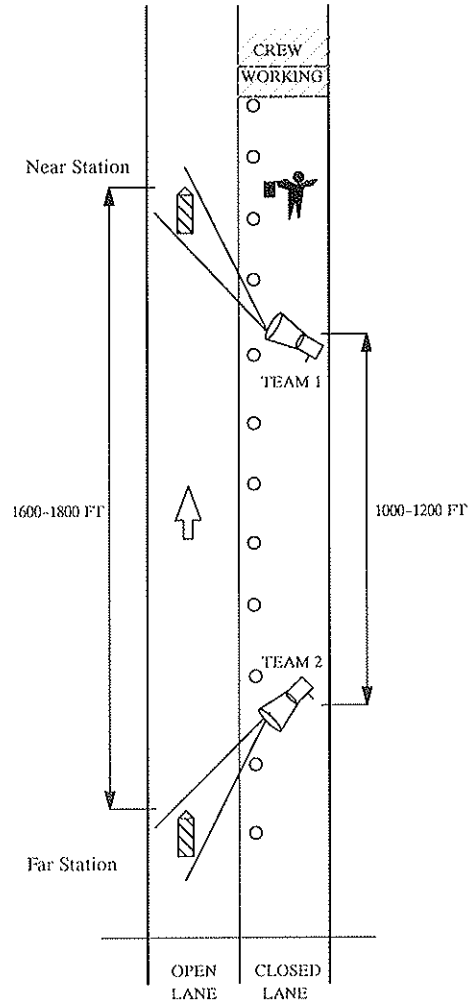


FIGURE 2 Data collection setup inside the construction zone.

The radar gun at the far station was pointed upstream and had a range of half a mile to a mile. It is assumed that vehicles that had radar detectors would receive the radars signal and that the drivers would slow down by the time they reached the far station. Drivers of vehicles that did not have radar detectors would not be influenced by the radar at either station. Thus, for both cases, any reaction to radar would take place before reaching the far station, and it is assumed that the use of radar guns did not influence the results of the study.

It is possible that the vehicle speeds were affected in the working area as a result of driving through the lane closure and that a speed difference between the far and near stations could be influenced by the lane closure. However, the locations of the far and near stations were a minimum of 1 mi downstream of the beginning of the lane closure, and it is probable that the drivers adjusted their speeds as a result of the lane closure before the far station. In the event that the

vehicle speeds were influenced by lane closure in the data collection area, this influence would be present both before and after the flagger was trained. Consequently, the influence of the lane closure would be the same both before and after training, and the net effect in the comparison of before and after training would be insignificant.

The two teams used their personal cars to collect the data. Each team consisted of two students, who stayed inside the car during the data collection periods. During data collection, one person activated the radar to measure the speed of the vehicles, and the other person wrote a description of the vehicles. The cars used were subcompact cars, which did not resemble police cars. There were no police on the northbound lanes during data collection. The cars were parked on the shoulder or the side of the road in the closed lane section. The vehicles of the construction crew were located close to those of the team. Drivers did not mistake the team cars for police cars.

DATA REDUCTION

The flagger effectiveness data were reduced in two parts: data from Station 1 were reduced using a Fortran program called TRAFFIC, whereas data from the far and near stations were reduced manually. The data from Station 1 gave the free flow traffic data outside of the construction zone for the desired time period. Free flow vehicles at Station 1 were considered to be those that had a minimum of 6 sec time headway between them and the preceding vehicle on that lane. Traffic data collected at Station 1 were the time a vehicle passed over the tubes, the vehicle speed, the number of axles, and the axle spacings. The TRAFFIC program, written at the University of Illinois specifically for this type of data reduction, separated the traffic data by lane, eliminated data that contained obvious errors, determined if a vehicle was moving at free flow or in a platoon, and then separated the records for the free flow vehicles for a give time period. The reduced data were also examined for any errors that the program may not have eliminated.

Speed reduction between the far and near stations was computed by subtracting speeds of the same vehicle at these two points. The information about each vehicle recorded by the two teams was matched for the near and far station descriptions to ensure that the speeds of the same vehicle were measured at the two locations. The team far from the flagger identified the vehicle whose speed was not influenced by the other vehicles in the work zone. The identified vehicles were either the lead vehicle in a platoon of vehicles of a vehicle traveling alone (not in a platoon). Once the vehicle was identified, the team far from the flagger would measure the speed of the vehicle and send a signal to the team near the flagger to measure speed of the vehicle and record type, color, and other descriptive information about the vehicle. The signal was either visual or audio. For each flagger, over 120 observations were made in before and after conditions. At both stations, the vehicles were not influenced by the vehicle ahead of them.

The data recorded by the two teams about the vehicles matched well. Comparing recorded time was helpful in matching the vehicles. Some data points were not used because the speed of the vehicle near the flagger was influenced by the presence of other vehicles. Every attempt was made to reduce the effect of a leading car on the speed of the following car. In the remaining observations, the speeds were not affected by the presence of other vehicles in the work zone. The descriptions of the vehicles recorded by the two teams were compared and if they did not match, the data were not used. Only the matching data points were used for further analysis.

DATA ANALYSIS OF THE EFFECTIVENESS OF FLAGGING

The effects of flagging before and after the training session are described for two cases for each flagger: (a) effect on cars only, and (b) effect on trucks only. For each case, the analysis consists of describing speed statistics for the vehicles before training, speed statistics for the vehicles after training, and a comparison of the statistics before and after training.

The speed statistics are calculated for Station 1, the far station, and the near station. The computed statistics are average speed, variance of speed, number of observations, difference between the mean speed and the speed limit, and the percentage of speeding vehicles. The average speeds, variances, and percentages exceeding the speed limit are used to evaluate the effect of the flaggers on vehicle speeds and the effect of the training session on the flaggers' effectiveness.

All statistical analyses were done on a microcomputer using the *Statistical Analysis System for Personal Computers* (PC–SAS). Three tests that were used in the statistical analysis are discussed briefly. The variances of speed of each group of data were compared to determine whether the shapes of the distributions of speeds for two conditions were significantly different from each other. An F-test was used for this comparison, with a 95 percent confidence level. The calculated F-value was

$$F = \frac{s_1^2}{s_2^2} \tag{1}$$

where

s_1^2 = variance of speeds for Case 1, and
s_2^2 = variance of speeds for Case 2.

The following distributions were compared using the F-test: the far station versus the near station for before-training conditions, the far station versus the near station for after-training conditions, the far station before training versus after training, and the near station before training versus after training. Making these comparisons allowed detecting a change in speed distributions and deciding what type of t-test to use for comparing average speeds. In the event that the distributions of speeds were not the same, an approximate value of t was used to reflect the difference in distributions (*10*).

A second test, the paired t-test, was used to compare speed reductions between the far and near stations, in which the speed observations were made for the same vehicle at both stations. The test was used in before- and after-training conditions. The t-value is computed as

$$t = \frac{\bar{d} - D_0}{s_d/n^{1/2}} \tag{2}$$

where

$\bar{d}$ = sample mean of the n differences,
s_d = standard deviation of the n differences,
n = number of pairs used, and
D_0 = expected speed difference.

The following comparisons were made using the paired t-test: the far station versus the near station before training, and the far station versus the near station after training.

In order to compare the average speeds before and after training, a third test, the t-test was used. The t-value was determined as

$$t = \frac{\bar{y}_1 - \bar{y}_2}{\left[\dfrac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}\right]^{1/2}\left(\dfrac{1}{n_1} + \dfrac{1}{n_2}\right)^{1/2}} \quad (3)$$

where $\bar{y}_1$ and $\bar{y}_2$ are the sample means, and n_1 and n_2 are the number of observations in each sample.

The t-test was used to make the following comparisons: the far station before training versus after training, the near station before training versus after training, and speed reduction between the far and near stations before training versus the speed reduction after training. The tests determined if the flagger was more effective in decreasing speeds after training and if the traffic was affected by the construction zone and radar differently before and after training at the far station.

The t-tests were made on the assumption that the speeds had a normal distribution. However, the t-tests were insensitive to the assumption of normal distributions (*11*). Consequently, the use of t-tests was acceptable in analyzing the data. The F-test was used to determine if the distributions were the same and which t-value should be used (*10*). Although the calculated and approximate t-values in the t-test were nearly identical, the approximated t-values were used when the distributions were not identical (*10*).

The speed reductions between station 1 and the near station were compared for before- and after-training conditions. This procedure determined the speed reduction that the flagger attained between a control station located outside the construction and a location close to the flagger. Finally, the percents of speeding vehicles were compared at the far and near stations before and after training.

The variances computed in the analysis were used to determine if the distributions of speeds were the same when comparing two different speed distributions. Garber and Gadirani (*12*) found that an increased variability in speeds is likely to increase accident frequency. The speeds of vehicles may exhibit an increased variance after training in comparison with before training, but the speed variance is irrelevant for this study because the data were collected for free flow vehicles only, and therefore the drivers would not be influenced by other vehicles. It is not known what the speed variance of all traffic is, but it was not the purpose of this study to increase the speed variance of vehicles. The purpose of using a flagger in a construction zone was to maintain speeds at the speed limit or at speeds appropriate for the construction area. If a flagger is effective, the speed of vehicles is uniform and the variance is small.

Effect on Cars Only

Effect of Flagger 1 on Cars Only

Flagger 1 Before the Training Session Flagger 1 was observed flagging from 8:05 to 9:35 a.m. on a Tuesday. At this time, the average speed of cars at the near station, on the basis of 58 free flow observations, was 40.27 mph. The variance of the speed was 36.12. The average speed was 4.73 mph less than the posted speed limit of 45 mph, and 20.69 percent of the drivers had speeds greater than the speed limit. At the far station, the average speed was 53.43 mph, and the speed variance was 32.03. The mean speed at the far station was 8.43 mph greater than the speed limit, with 84.48 percent of the drivers exceeding the speed limit. The mean speed at Station 1 was 73.33 mph, on the basis of 156 free flow car observations. The speed variance was 38.06 mph. The average speed was 8.33 mph greater than the speed limit, and 99.36 percent of the observations showed speeds exceeding the speed limit.

Flagger 1 After the Training Session After the training session, Flagger 1 was observed from 1:15 to 2:45 p.m. on a Tuesday. At the near station, the average speed was 35.02 mph and the speed variance was 53.14. The average speed was 9.98 mph less than the speed limit, and 5.38 percent of the cars had speeds exceeding the speed limit. At the far station, the average speed was 48.63 mph and the variance was 34.33. The average speed was 3.63 mph greater than the speed limit, and 64.52 percent of the cars were speeding. At both the near and far stations, there were 93 observations of free flow cars and the speed limit was 45 mph. At Station 1, there were 163 free flow car observations, and the speed limit was 65 mph. The average speed was 75.34 mph and the variance of the speed was 38.68. The average speed was 10.34 mph greater than the speed limit, and 93.25 percent of the cars were speeding. Table 1 presents speed statistics calculated for Flagger 1 before and after training.

Comparison of Before and After Training The speed variances at the far and near stations before and after training were compared using F-tests with 95 percent confidence level. The speed distributions before training at each station were not significantly different from each other (F = 36.12/32.03 = 1.127). The speed distributions at the far and near stations after training were significantly different from each other (F = 53.14/34.33 = 1.548). This difference indicates that in the after-training condition, the speed of vehicles near the flagger had a distribution with a wider range about the mean than the distribution at the far station.

A comparison of the speed variance at the near station before and after training was made. The F-value of 1.4712 (53.14/36.12) indicates that there was a significant difference in the speed variances, with the after-training condition indicating a greater dispersion about its mean than did the before-training condition. A similar test was performed at the far station. The test showed that there was no significant difference in the speed distributions at the far station before and after training (F = 34.33/32.03 = 1.0718). The distribu-

TABLE 1 SPEED STATISTICS FOR CARS ONLY, FLAGGER 1 AND FLAGGER 2 BEFORE AND AFTER THE TRAINING SESSION

	FLAGGER 1			FLAGGER 2		
	Station 1	Far Station	Near Station	Station 1	Far Station	Near Station
Speed Limit	55 mph	45 mph	45 mph	55 mph	45 mph	45 mph
Before Training						
Mean Speed	73.33	53.43	40.27	75.82	51.53	41.39
Variance	38.06	32.03	36.12	42.64	25.40	43.82
Number of Observations	156	58	58	245	66	66
Mean Speed - Speed Limit	8.33	8.43	-4.73	10.82	6.53	-3.61
Percent of Speeding Cars	99.36	84.48	20.69	93.06	87.88	25.76
After Training						
Mean Speed	75.34	48.63	35.02	72.86	51.69	35.59
Variance	38.68	34.33	53.14	32.14	39.81	51.40
Number of Observations	163	93	93	193	92	92
Mean Speed - Speed Limit	10.34	3.63	-9.98	7.86	6.69	-9.41
Percent of Speeding Cars	93.25	64.52	5.38	88.60	83.70	8.70

tions of speeds at the far and near stations before and after training, shown in Figures 3 and 4, indicate that there was a shift toward lower speeds in the after training conditions at both stations.

The speed reductions between far and near stations were compared for before and after training. The speed reduction in the before-training session was 12.23 mph, and in the after-training period it was 13.61 mph. The amount of speed reduction before training was compared to the speed reduction after training, using a t-test with a 95 percent confidence level. The t-test indicated that there was no significant difference in amount of speed reduction before and after training (t = 0.4052). Thus, the speed reduction before training was not different from the speed reduction after training. The distributions of speed reductions between the far and near stations before and after training are shown in Figure 5.

At the near station and the far station, the average speeds before and after training were compared using a 95 percent confidence level. A t-test indicated that there was a significant difference in the speeds at the near station before and after training (t = − 4.5970), and that the average speed after training was 5.25 mph less than the speed before training. A similar test was performed on the data at the far station. The t-test showed that there was also a significant difference in the average car speeds at the far station before and after training (t = − 4.9540), with the average speed after training being 4.80 mph less than the average speed before training.

The analysis indicates that the speed reduction between the far and near stations was the same before and after training. The average speeds at each station were about 5 mph less after training than before. The speed reduction at the far station after training is not attributed to the flagger. It is possible that the flagger had an increased effectiveness in decreasing the speeds at the near station after training by an additional 5.25 mph, but the reduced speeds may also be a result of slower-moving traffic in the construction zone.

There was a 33.06-mph speed reduction between Station 1 and the near station before training. The speed reduction between Station 1 and the near station after training was 40.32 mph. The speed reduction between the two stations was 7.26 mph greater after training than it was before training. The average speed of cars at Station 1 in the after-training period was only slightly higher than the before-training period, and thus it appears that the increased amount of speed reduction took place at the near station. However, the average speed at the far station was less in the after-training period than it was in the before-training period and consequently, the increased amount of speed reduction cannot be attributed to the near station only. Figure 6 shows the speed profile of the cars as they pass Station 1, the far station, and the near station.

Effect of Flagger 2 on Cars Only

Flagger 2 Before the Training Session Data for Flagger 2 before the training session were collected from 2:15 to 3:45 p.m. on a Monday. At this time, the average speed of free flow cars at the near station was 41.39 mph, and the variance of speed was 43.82. The mean speed was 3.61 mph less than the speed limit, and 25.76 percent of the cars were speeding. At the far station, the average speed was 51.53 mph and the speed variance was 25.40. The average speed exceeded the speed limit by 6.53 mph, and 87.88 percent of the cars had speeds greater than the speed limit. There were 66 observations at both the far and near stations, and the speed limit was 45 mph. At Station 1, the speed limit was 65 mph. There were 245 observations of free flow cars, and the average speed was 75.82 mph. The speed variance was 42.64. The mean speed was 10.82 mph greater than the speed limit, and 93.06 percent of the observations had speeds exceeding the speed limit.

Flagger 2 After the Training Session Flagger 2 was observed after the training session from 1:15 to 2:45 p.m. on Wednesday. On the basis of 92 observations at the near station, the average speed was 35.59 mph, and the speed variance was 51.40. The 45-mph speed limit was 9.41 mph greater than

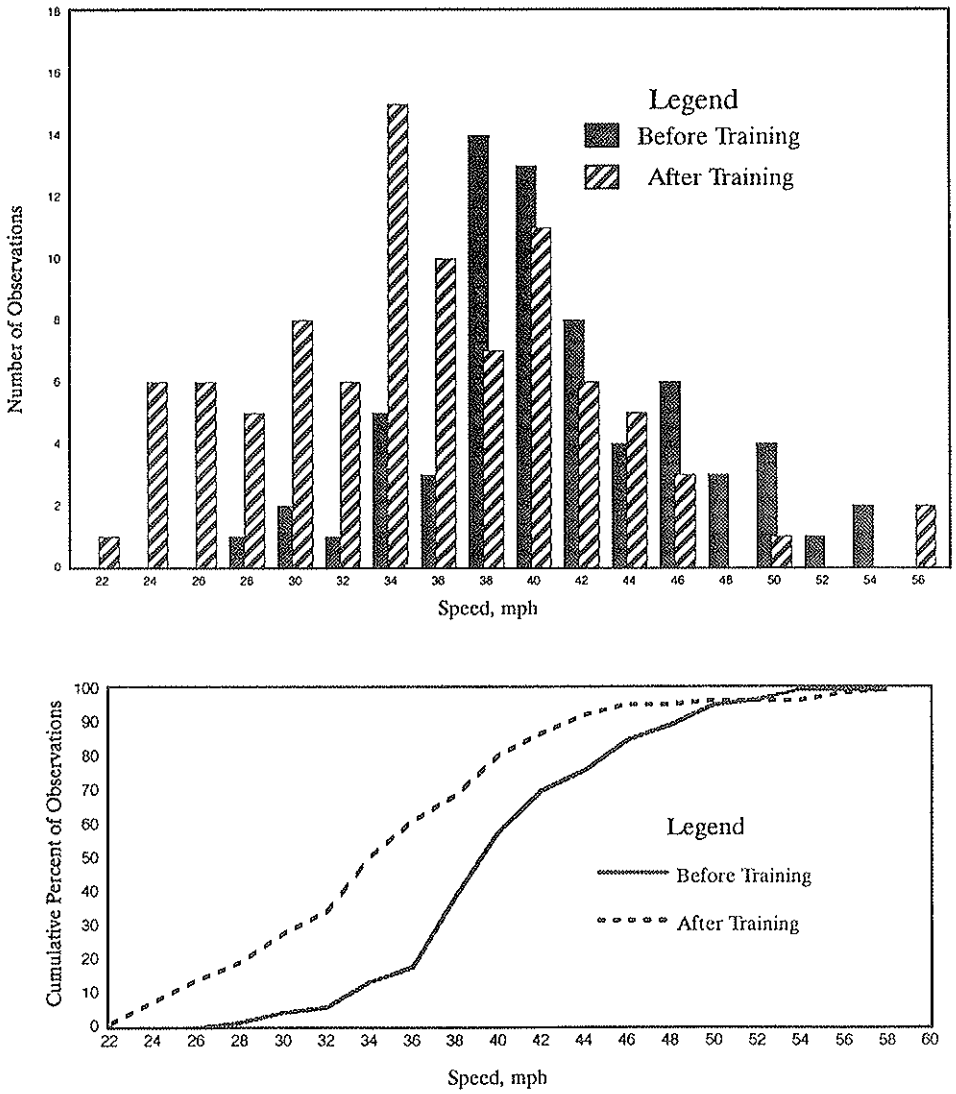


FIGURE 3 Speed distributions of cars only at the near station before and after training for Flagger 1.

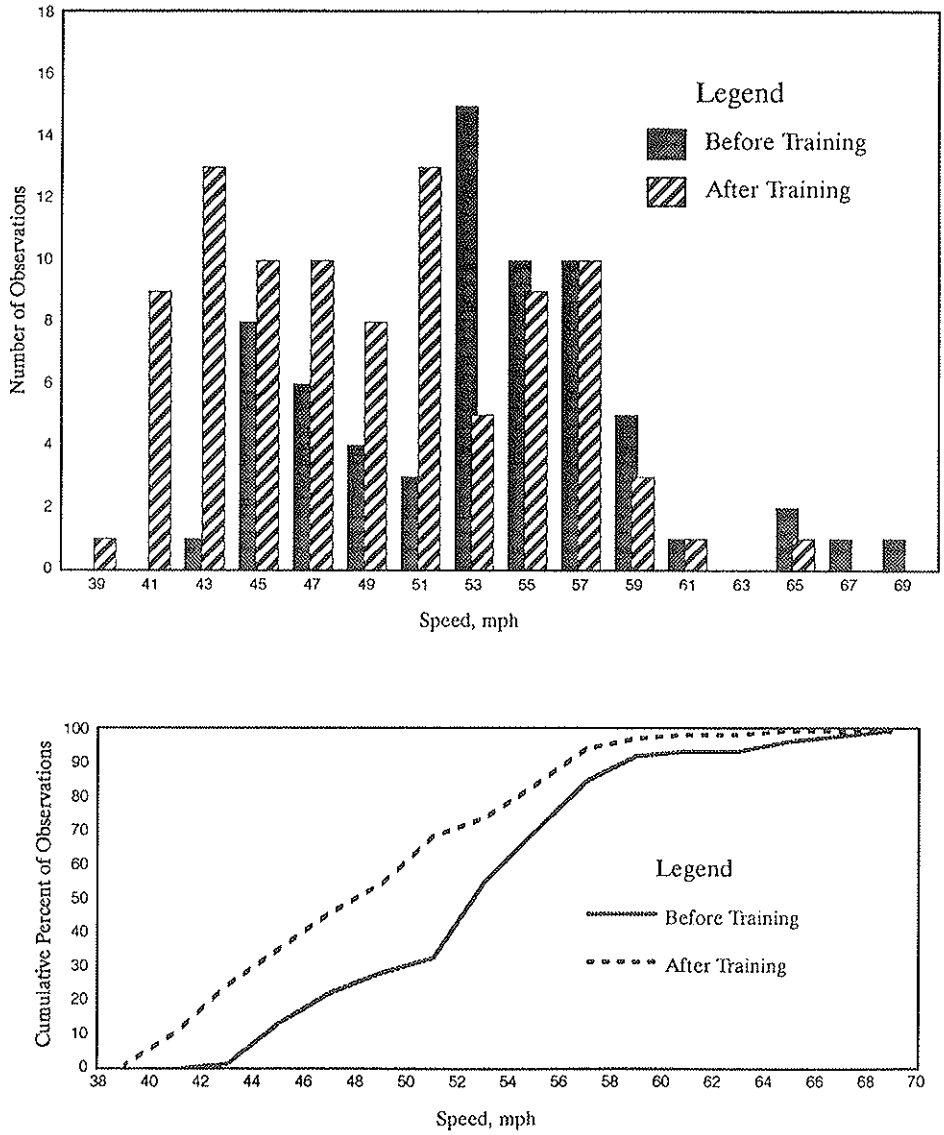


FIGURE 4 Speed distributions of cars only at the far station before and after training for Flagger 1.

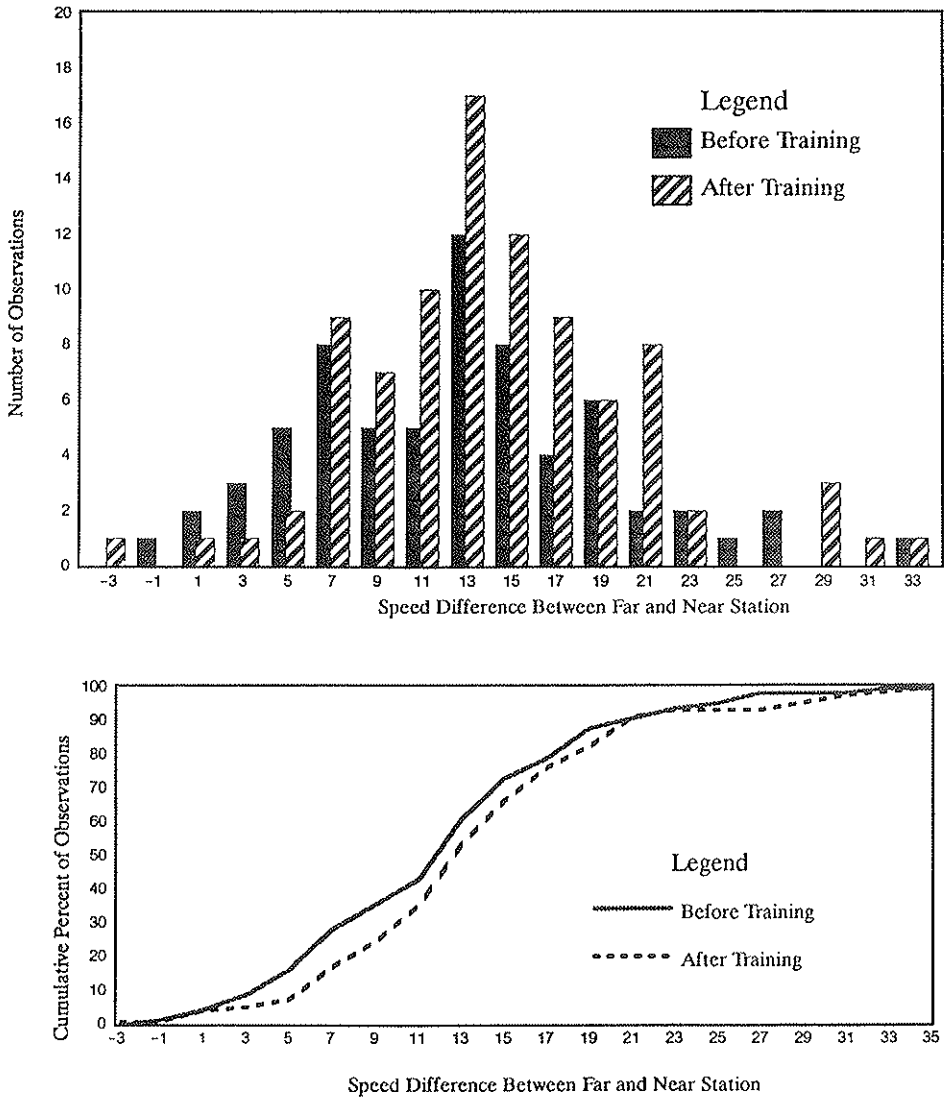


FIGURE 5 Distributions of speed reductions of cars only between the near and far stations before and after training for Flagger 1.

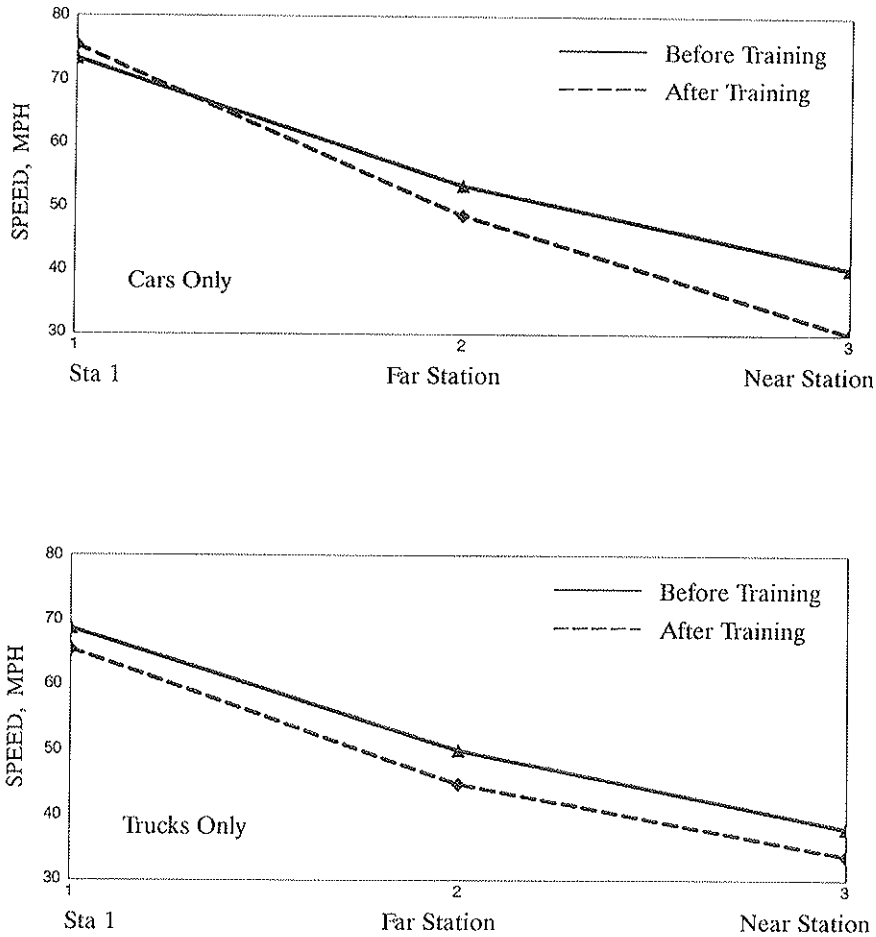


FIGURE 6 Speed profiles of cars (*top*) and trucks (*bottom*) at Station 1, the far station, and the near station for Flagger 1.

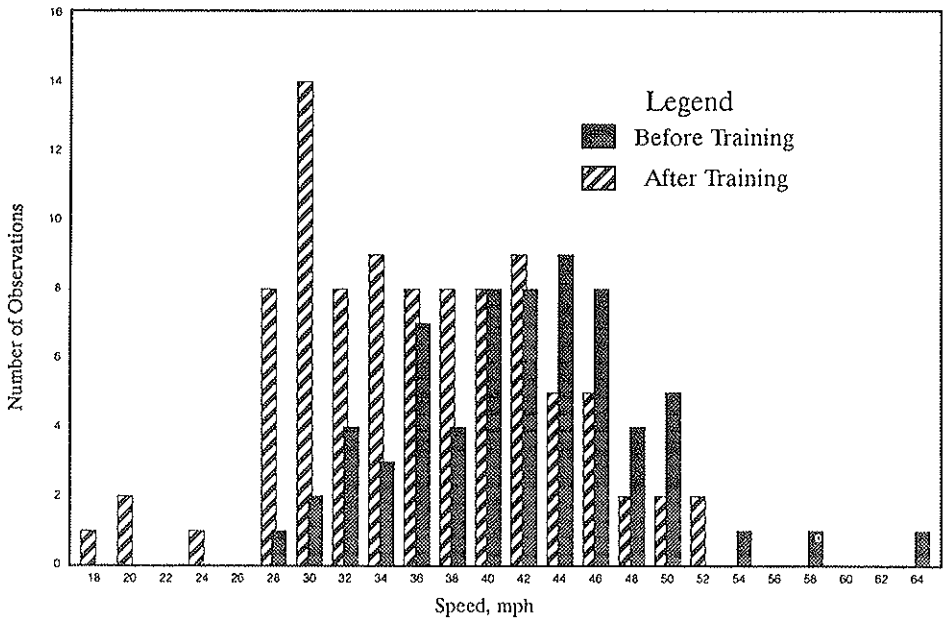
the average speed. The percentage of speeding cars was 8.70 percent. At the far station, the average speed was 51.69 mph and the speed variance was 39.81. The mean speed was 6.69 mph greater than the speed limit, with 83.70 percent of the observations having speeds greater than the speed limit. There were 92 observations at the far station. The mean speed at Station 1 was 72.86 mph, with a variance of 32.14. This average is based on 193 observations of free flow cars. The average speed was 7.86 greater than the speed limit, and 88.60 percent of the vehicles exceeded the speed limit. Speed statistics for Flagger 2 before and after training are presented in Table 1.

Comparison of Before and After Training An F-test comparing the speed variance at Station F and the near station before training indicated that the speed distributions were significantly different from each other (F = 43.82/25.40 = 1.7252), and that the distribution at the near station had a wider dispersion than the distribution at the far station. However, the distributions of speeds at the far and near stations after training were not significantly different from each other (F = 51.40/39.81 = 1.2911).

The variances at the near station were compared for before and after training conditions. There was no significant difference in the distribution of speeds before and after training (F = 51.40/43.82 = 1.1730). However, there was a significant difference in the distribution of variances at the far station before and after training (F = 39.81/25.40 = 1.5673). The range of the distribution of speeds after training was greater than the distribution before training. The distribution of speeds before and after training at the near and far stations are shown in Figures 7 and 8.

The speed reductions between the two stations were compared for before- and after-training conditions using a paired t-test. Before training, the average speed reduction between the far and near stations was 10.13 mph. After training, the speed reduction was 16.09 mph. The results of the test indicate that there was a significant difference in the speed reduction (t = 5.09), where the speed reduction after training was 5.96 mph greater than the speed reduction before training. Figure 9 shows the distribution of speed reductions before and after training.

The average speeds of the car observations at the near station were compared for before and after training using a t-test with a 95 percent confidence level. There was a significant difference in the speeds (t = −5.16), where the average speed of the cars after training was 8.80 mph less than before training. A similar test was used at the far station. There was no significant difference in speeds (t = 0.1827). The average



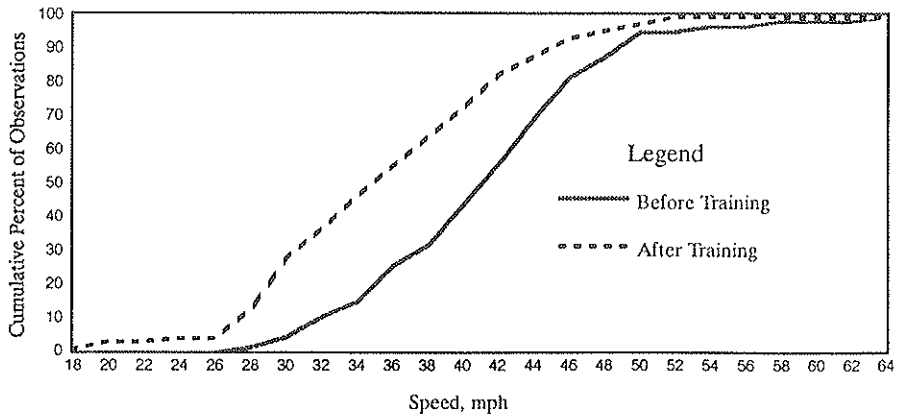


FIGURE 7 Speed distributions of cars only at the near station before and after training for Flagger 2.

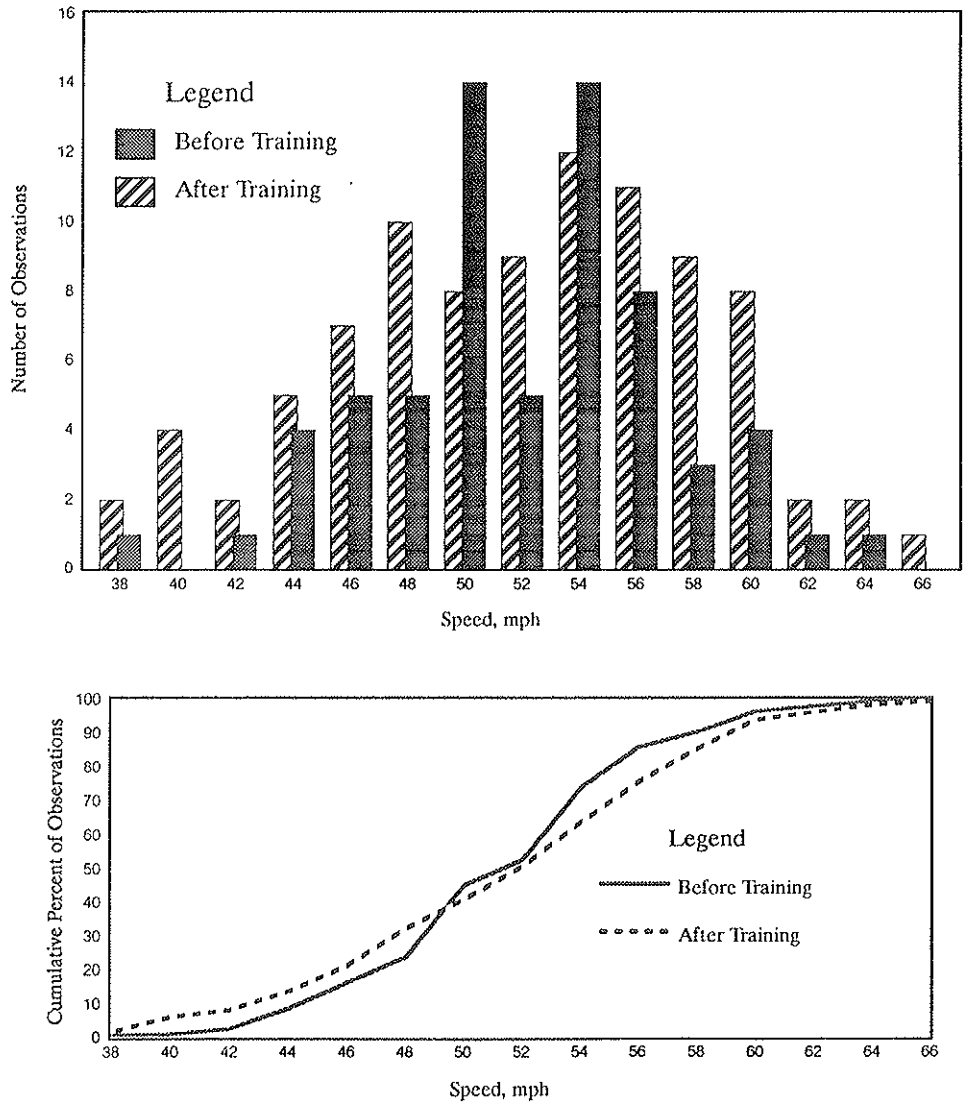


FIGURE 8 Speed distributions of cars only at the far station before and after training for Flagger 2.

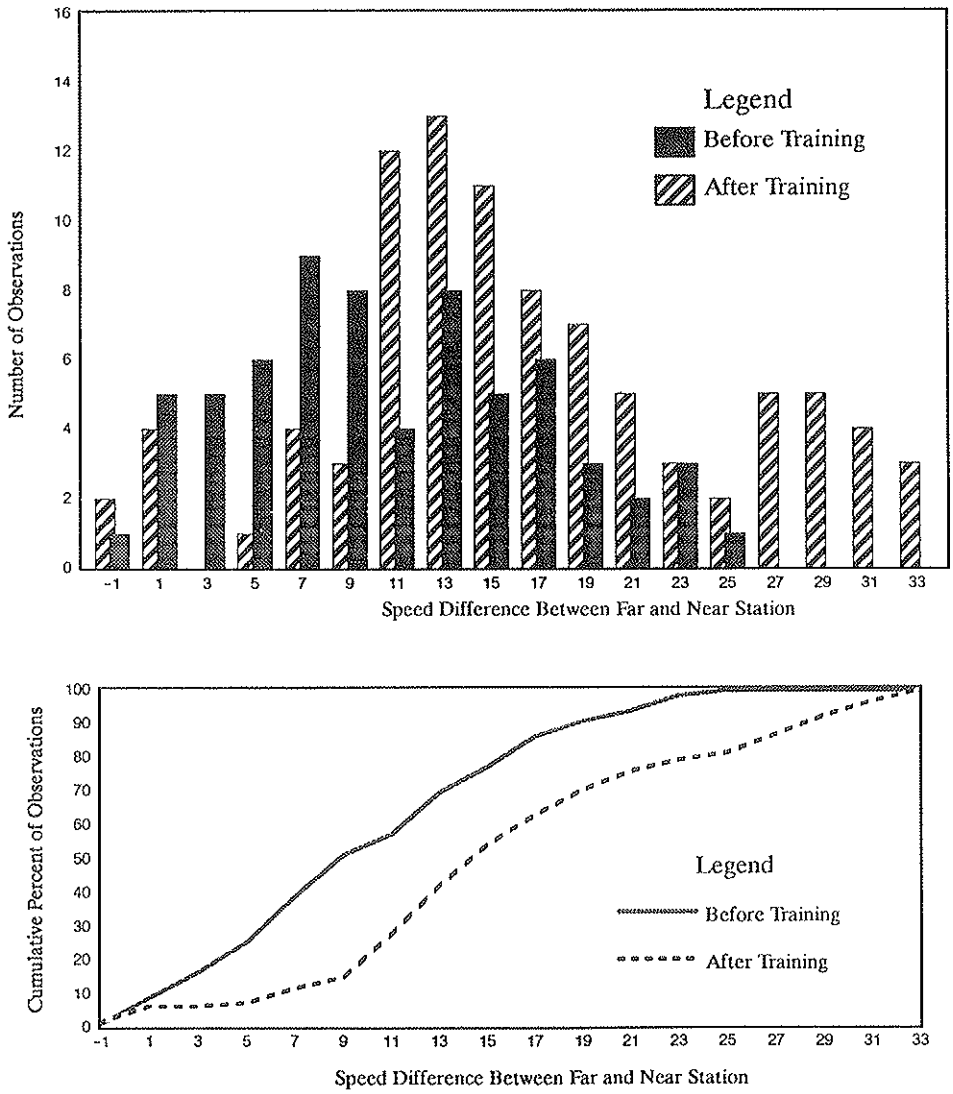


FIGURE 9 Distributions of speed reductions of cars only between the near and far stations before and after training for Flagger 2.

speed at the far station before training was not different from the average speed after training.

The average speed of free flow cars at Station 1 was only slightly less in the before-training period than in the after-training period. However, the average speed of cars at the far station was the same for before and after training. Consequently, it appears that the decrease in speed at the near station in the after-training condition, compared to before training, is attributed to an increased effectiveness of Flagger 2.

Before training, there was a 34.43-mph speed reduction between Station 1 and the near station. After training, the speed reduction was 37.27 mph. Hence, the speed reduction after training was 2.84 mph greater than before training. Because the average speed of cars at the far station was the same before and after training, it is possible that the increased speed reduction between the control station and the near station may be attributed to Flagger 2. Speed profiles of cars at Station 1, the far station, and the near station before and after training for Flagger 2 are shown in Figure 10.

Effect on Trucks Only

Effect of Flagger 1 on Trucks Only

Flagger 1 Before the Training Session The average speed at the near station before the training session was 37.93 mph and the variance was 30.47. The average speed was 7.07 mph less than the speed limit, although 6.67 percent of the trucks were traveling faster than the speed limit. At the far station, the average speed was 49.93 mph, and the speed variance was 26.73. The speed limit at the far and near stations was 45 mph, and the number of observations of free flow trucks was 30. The mean speed was 4.93 mph greater than the speed limit, with 83.33 percent of the trucks exceeding the speed limit. At Station 1, there were 45 observations of free flow trucks. The average speed was 68.69 mph, and the variance was 23.52. The average speed was 13.68 mph greater than the speed limit, and 100 percent of the trucks were speeding. The speed limit at Station 1 was 55 mph.

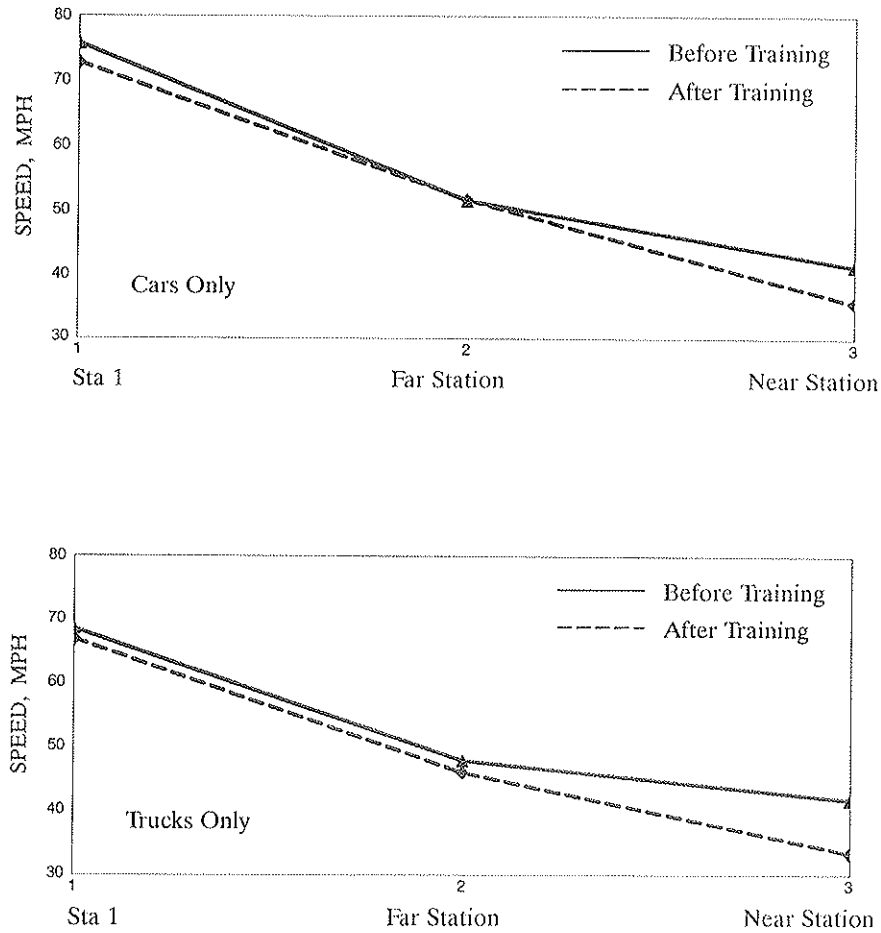


FIGURE 10 Speed profiles of cars (*top*) and trucks (*bottom*) at Station 1, the far station, and the near station for Flagger 2.

Flagger 1 After the Training Session After the training session, the average speed at the near station, based on 32 observations, was 35.59 mph and the speed variance was 43.82. The mean speed was 11.41 mph less than the speed limit of 45 mph, and 3.13 percent of the trucks were traveling faster than the speed limit. At the far station, the mean speed was 44.75 mph and the variance was 14.59. The average speed was 0.25 mph less than the speed limit, and 40.63 percent of the trucks were speeding. Based on 47 free flow observations, the mean speed at Station 1 was 65.44 mph, and the variance was 45.42. The average speed was 10.44 mph greater than the speed limit of 55 mph, and the percentage of speeding trucks was 95.74 percent. Speed statistics for Flagger 1 for trucks before and after training are presented in Table 2.

Comparison of Before and After Training The variances of speed at the far and near stations were compared using an F-test. The results of the test indicate that for before-training conditions, there was no significant difference in the variances at the far station and the near station ($F = 36.47/26.73 = 1.1399$). However, there is a significant difference in the distribution of speeds at both stations after training ($F = 43.82/14.59 = 3.0034$), indicating that the range of the distribution of speeds at the near station after training is greater than the range of the distribution at the far station.

The variances at the near station were compared for before and after training. An F-test indicated that there was no significant difference in the distribution of speeds before and after training ($F = 43.82/30.47 = 1.4381$). Likewise, there was no significant difference in the distributions at the far station before and after training ($F = 26.73/14.59 = 1.4381$). The distributions of truck speeds at the near and far stations before and after training are shown in Figures 11 and 12.

The speed reductions between the far and near stations were 12.00 mph before and 11.16 mph after the training session. The speed reductions were compared for before and after training, and there was no significant difference between before and after training conditions ($t = -0.4092$). The speeds at the near station were compared for before and after training, and there was a significant difference in speeds ($t = -2.79$), where the average speed after training was 4.34 mph less than before training. There was also a significant difference in the speeds at the far station before and after training ($t = -4.5050$), with the speed after training being 5.18 mph less than before training. The distribution of speed reduction before and after training is shown in Figure 13.

TABLE 2 SPEED STATISTICS FOR TRUCKS ONLY, FLAGGER 1 AND FLAGGER 2 BEFORE AND AFTER THE TRAINING SESSION

	FLAGGER 1			FLAGGER 2		
	Station 1	Far Station	Near Station	Station 1	Far Station	Near Station
Speed Limit	55 mph	45 mph	45 mph	55 mph	45 mph	45 mph
Before Training						
Mean Speed	68.69	49.93	37.93	68.43	47.79	41.61
Variance	23.52	26.73	30.47	18.74	22.46	32.03
Number of Observations	45	30	30	55	34	34
Mean Speed – Speed Limit	13.68	4.93	-7.07	13.43	2.79	-3.39
Percent of Speeding Trucks	100	83.33	6.67	100	73.53	20.59
After Training						
Mean Speed	65.44	44.75	33.59	66.82	45.94	33.19
Variance	45.42	14.59	43.82	18.83	25.70	27.98
Number of Observations	47	32	32	72	52	52
Mean Speed – Speed Limit	10.44	-0.25	-11.41	11.82	0.94	-11.81
Percent of Speeding Trucks	95.74	40.63	3.13	100	46.15	0.00

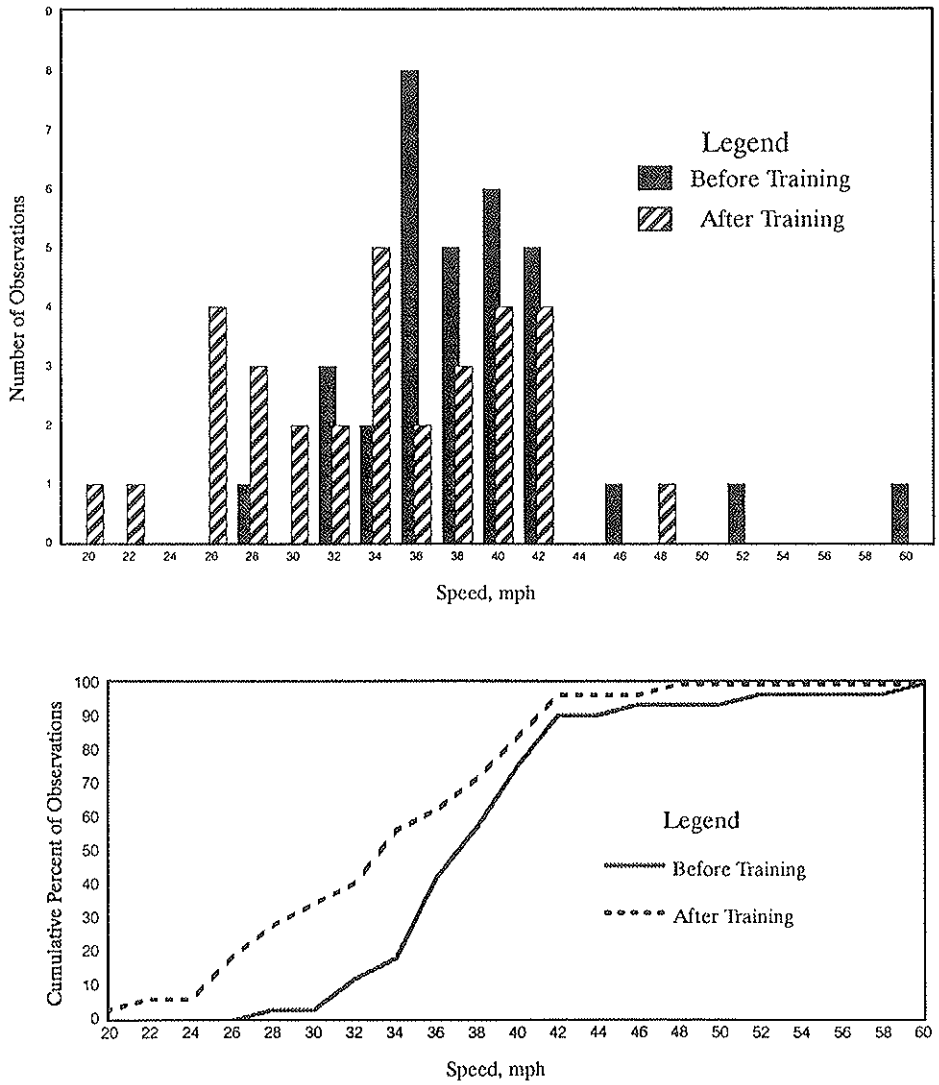


FIGURE 11 Speed distributions of trucks only at the near station before and after training for Flagger 1.

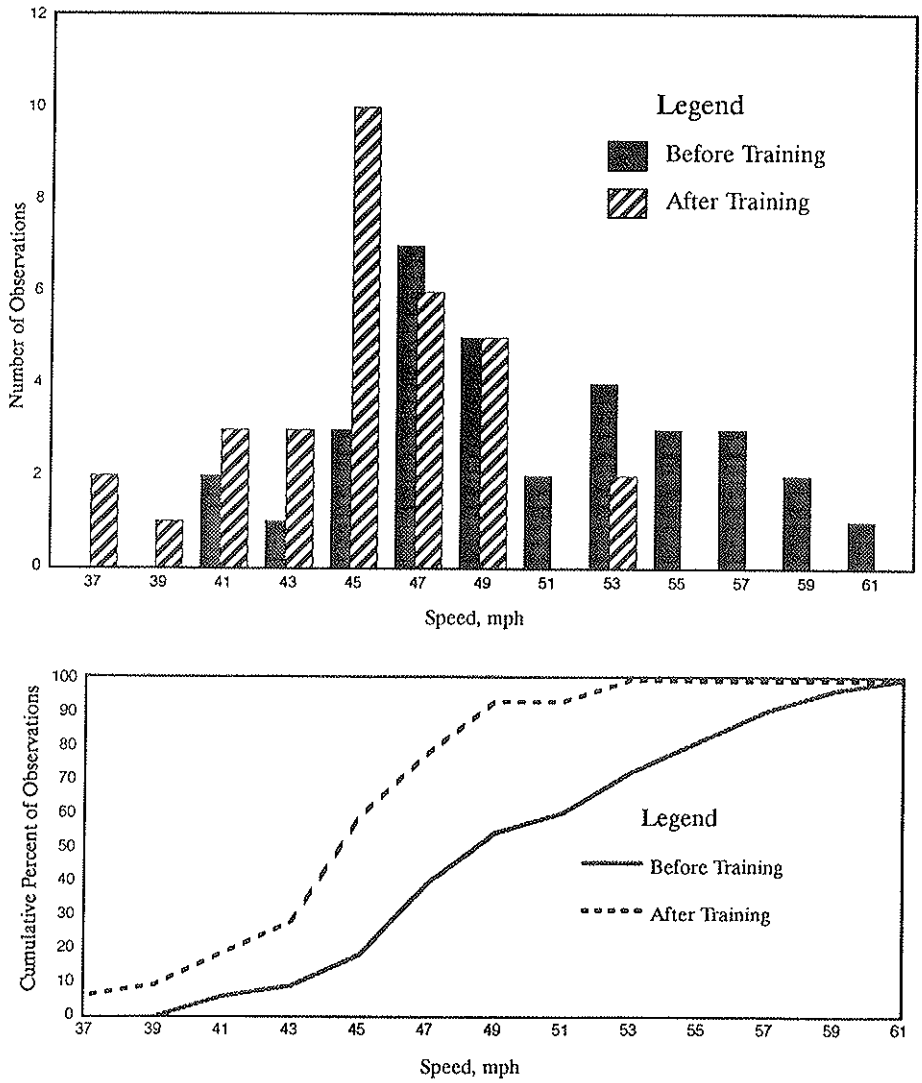


FIGURE 12 Speed distributions of trucks only at the far station before and after training for Flagger 1.

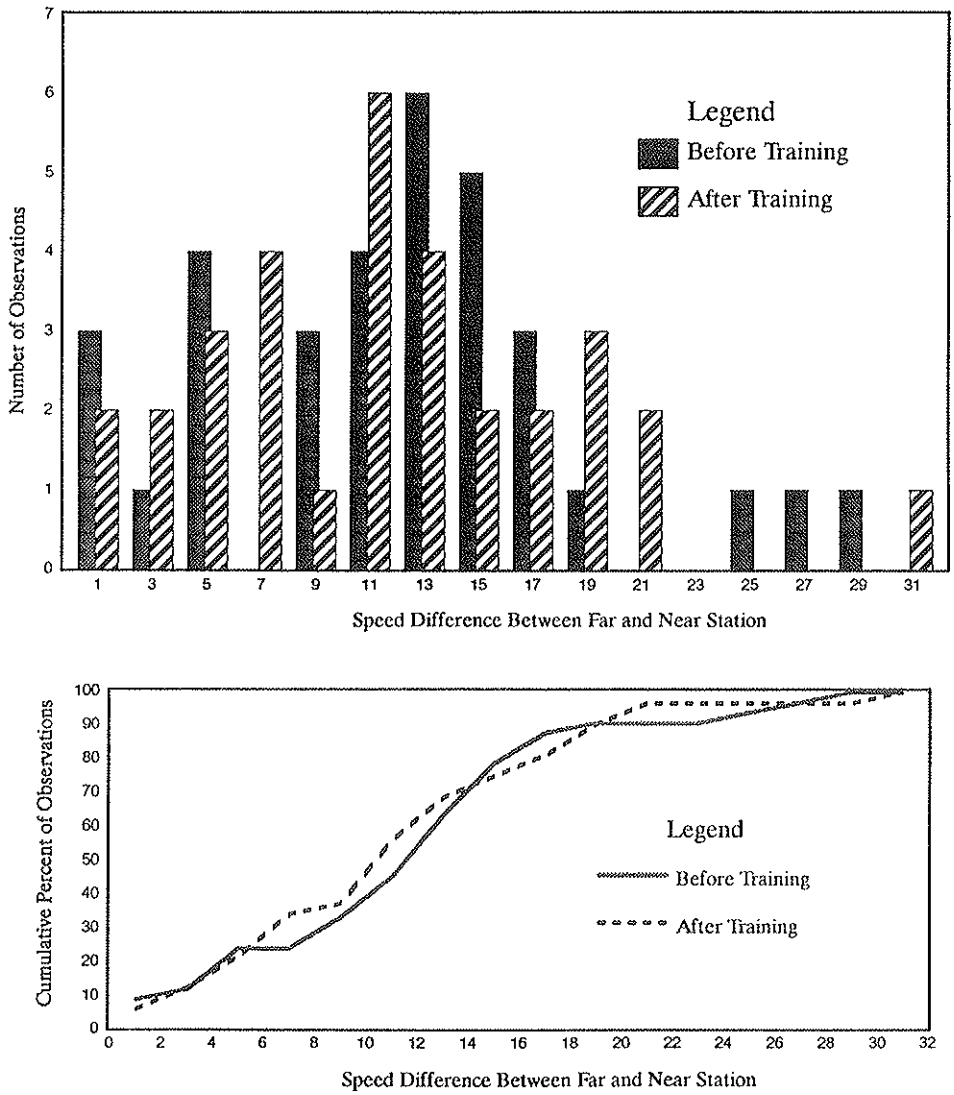


FIGURE 13 Distributions of speed reductions of trucks only between the far and near stations before and after training for Flagger 1.

The analysis shows that for after-training conditions, the average speeds of trucks at Station 1, the far station, and the near station, were less than their respective speeds before training. Consequently, although the decreased speed at the near station after training may be a result of an increased effectiveness of Flagger 1 after training, it is also possible that the decreased speed may be a result of a generally slower-moving traffic.

The speed reduction between Station 1 and the near station before training was 30.70 mph. After training, the speed reduction was 31.85 mph. There was a 1.09-mph greater speed reduction between the two stations after training than there was before. Because the speed reduction after training was not much greater than in the before-training period, it appears that the training session had little effect on the speed reduction between the control station and the near station. Speed profiles of trucks at Station 1, the far station, and the near station before and after training for Flagger 1 are shown in Figure 6.

Effect of Flagger 2 on Trucks Only

Flagger 2 Before the Training Session The average speed at the near station was 41.61 mph, and the speed variance was 32.03. This result is based on 34 free flow truck observations. The average speed was 3.39 mph less than the speed limit of 45 mph, and 20.59 percent of the trucks had speeds exceeding the speed limit. At the far station, the average speed was 47.79 mph and the variance was 22.46. The mean speed was 2.79 mph greater than the speed limit, and 75.03 percent of the trucks were speeding. The average speed at Station 1, on the basis of 55 free flow observations, was 68.43 mph. The speed variance was 18.74. The average speed was 13.43 mph greater than the speed limit, and all of the trucks (100 percent) were speeding.

Flagger 2 After the Training Session At the near station, the average speed of trucks after the flagger was trained was

33.19 mph, and the speed variance was 27.98. The average speed was 11.81 mph less than the speed limit, and there were not any trucks speeding (0.00 percent). At the far station, the average speed was 45.94 mph and the variance was 25.70. The average speed was 0.94 mph greater than the speed limit, and 46.15 percent of the trucks were speeding. At both the far and near stations there were 52 truck observations, and the speed limit was 45 mph. At Station 1, the average speed, on the basis of 72 free flow truck observations, was 66.82 mph, and the variance was 18.83. The average speed was 11.82 mph greater than the posted speed limit of 55 mph, and 100 percent of the trucks had speeds exceeding the speed limit. Speed statistics for trucks affected by Flagger 2 are presented in Table 2.

Comparison of Before and After Training The variances at the far and near stations were compared for before training conditions using an F-test with 95 percent confidence level. The test shows that the distributions at each station were not significantly different from each other (F = 32.03/22.46 = 1.4261). A similar test was used on the speed variances at the far and the near stations after training, and it indicated that there was no significant difference in the speed distributions at both stations (F = 27.98/25.70 = 1.0887). Thus, the distributions of speeds before and after training at the near station were not different from the distributions at the far station.

The speed variance at the near station before training was compared with the variance at the near station after training using an F-test with a 95 percent confidence level. The results indicated that the distributions of the speeds at the near station were not significantly different from each other before and after training (F = 32.03/27.98 = 1.1447). Likewise, the same test at the far station indicated that there was no significant difference in the distribution of speeds before and after training (F = 25.70/22.46 = 1.1443). The distributions of speeds at the near station before and after training are shown in Figure 14, and distributions at the far station before and after training are shown in Figure 15.

The speed reduction between the far station and the near station before training was 6.18 mph. After training, the speed

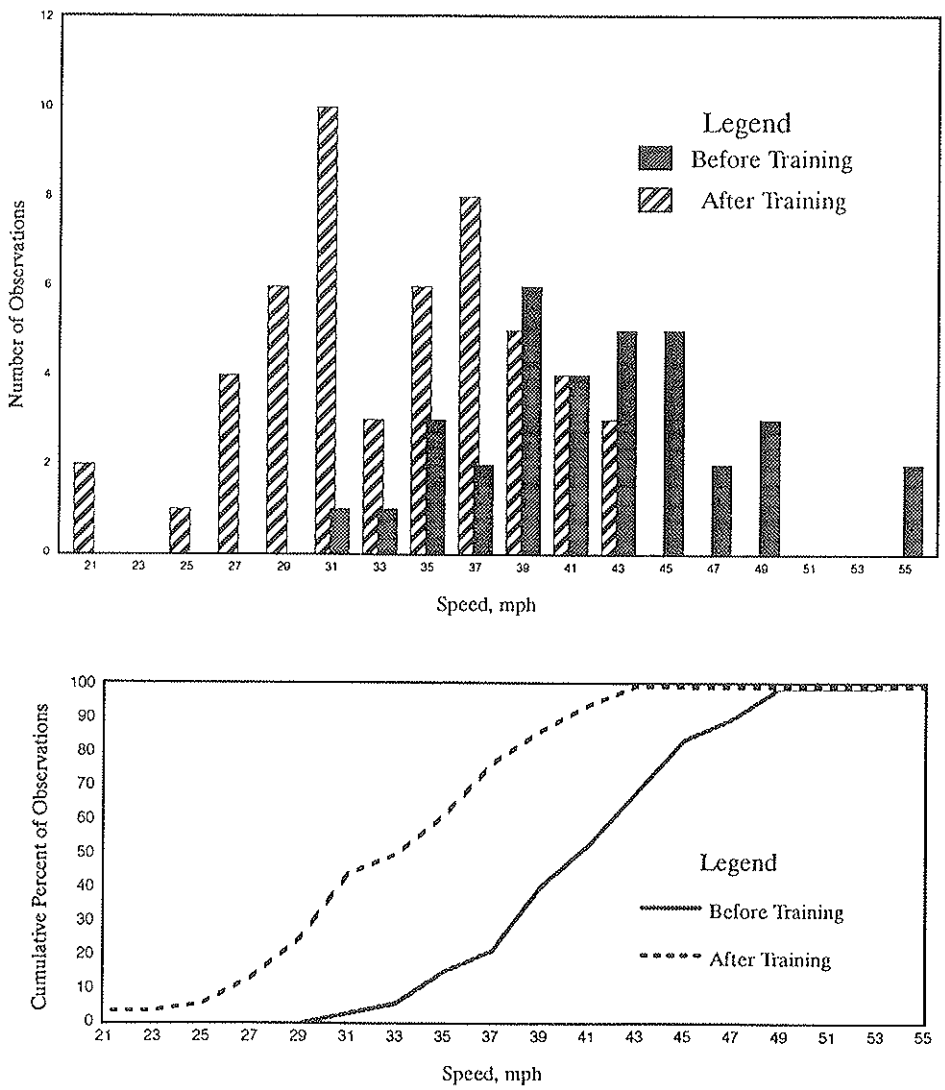


FIGURE 14 Speed distributions of trucks only at the near station before and after training for Flagger 2.

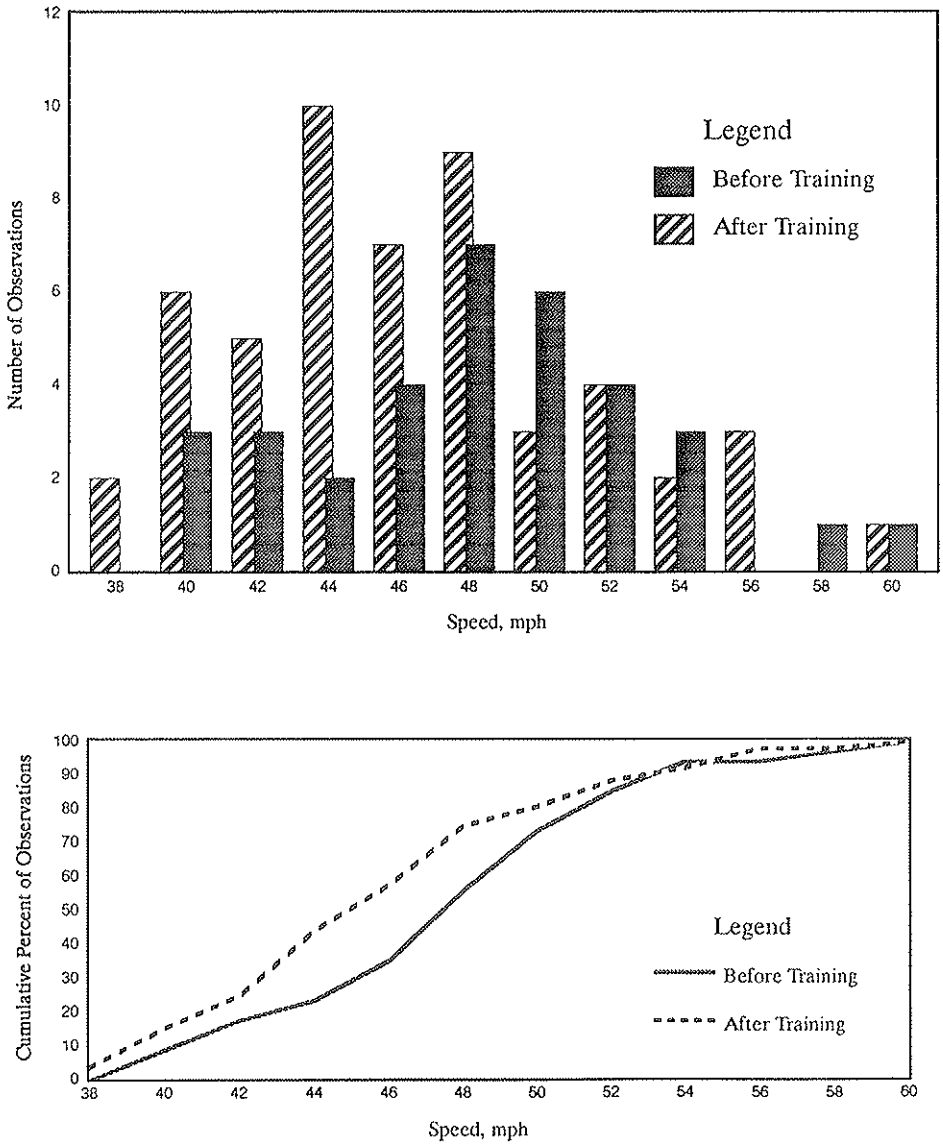


FIGURE 15 Speed distributions of trucks only at the far station before and after training for Flagger 2.

reduction between the two stations was 12.75 mph. The speed reductions before and after training were compared using a t-test with a 95 percent confidence level. The results indicate that there was a significant difference in the amount of speed reduction ($t = 5.77$). Thus, the speed reduction between the far and near stations was 6.58 mph more after training than it was before training. The distributions of speed reduction of trucks before and after training are shown in Figure 16.

The speeds at the far station were compared for before- and after-training conditions using a t-test with a 95 percent confidence level. There was no significant difference in speeds before and after training ($t = 0.0934$). However, a similar test used at the near station indicated that there was a significant difference in speeds before and after training ($t = -7.0191$). Thus, the average speed of free flow trucks at the near station after training was 8.42 mph less than the average speed before training.

The analysis indicates that the average speed at Station 1 after training was slightly less than before training, that the average speed at the far station was the same before and after training, and that the average speed at the near station was significantly lower after training than before. It is possible that because the speeds of trucks were the same at the far station, the speed reduction at the near station is a result of an increased effectiveness of Flagger 2 after the training session.

There was a 26.82-mph speed reduction between Station 1 and the near station before training. After training the speed reduction between the two stations was 33.63 mph. The speed reduction between the two stations was 6.81 mph greater after training than before training. The speeds at Station 1 before and after training were nearly the same (after training was 1.61 mph less than before training), and the speeds at the far station before and after training were the same. Thus, drivers in the after-training period were not considered to be slower-

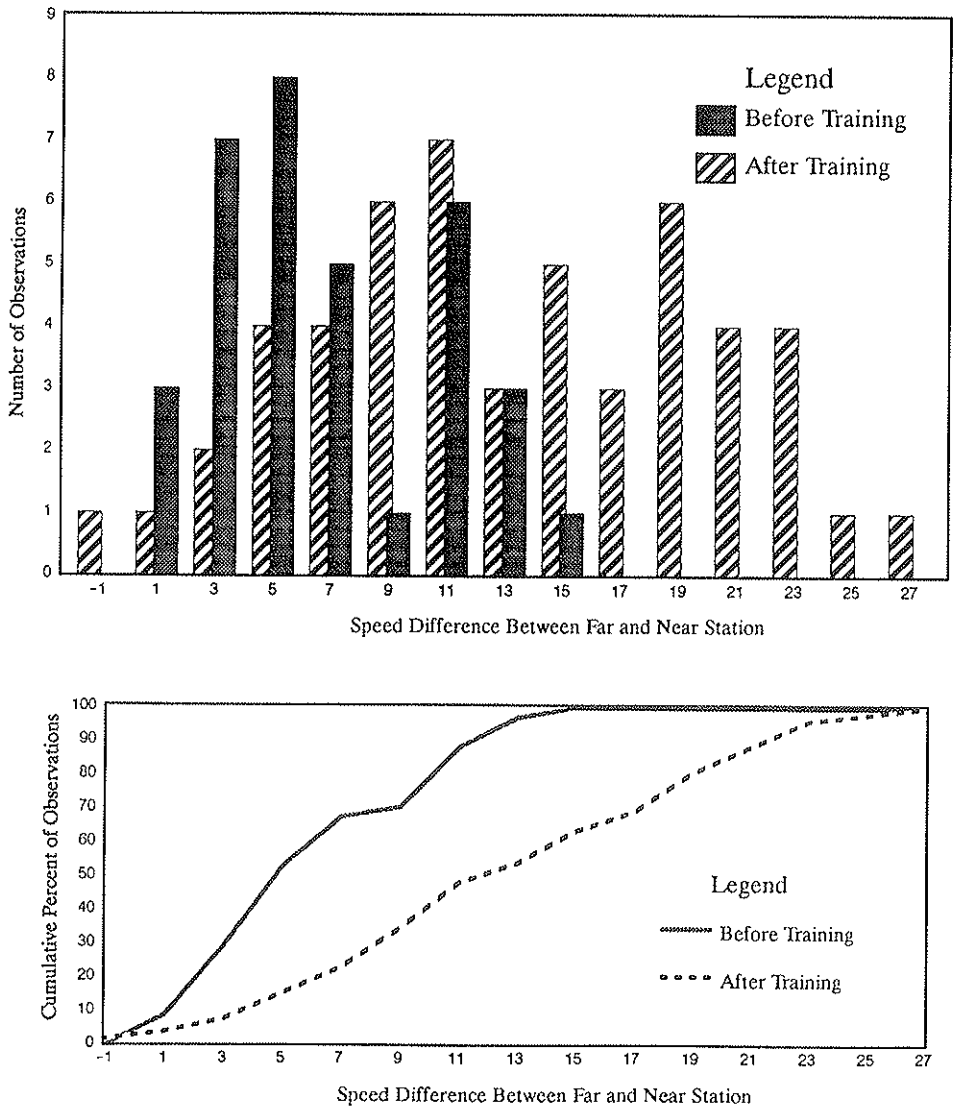


FIGURE 16 Distributions of speed reductions of trucks only between the far and near stations before and after training for Flagger 2.

moving traffic, and it considered likely that the greater speed reduction after training was a result of an increased effectiveness of Flagger 2. Figure 10 shows speed profiles of trucks at Station 1, the far station, and the near station for Flagger 2 before and after training.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicate that there was a decrease in the average speed of trucks and cars as they approached the flagger both before and after the flagger received training. Both cars and trucks had speeds exceeding the speed limit at Station 1, outside of the construction zone, and at the far station, inside of the construction zone. However, at the near station, inside of the construction zone, the average speed of free flow vehicles was well below the posted speed limit. At 1600 to 1800 feet upstream of the flagger and inside of the construction zone, the cars and trucks were traveling an average of 7.5 and 3.9 mph faster than the speed limit before training, respectively. After the training session, the cars and trucks were traveling 5.2 and 0.3 mph faster than the speed limit, respectively. Near to the flagger, the average speeds of cars and trucks were 4.2 and 5.2 mph less than the speed limit in before-training conditions, while they were traveling 9.7 and 11.6 mph less than the speed limit in after-training conditions, respectively.

For both cars and trucks, the speed of vehicles near to the flagger is less in the after-training period than in the before-training period. For cars, the speed reduction between before and after training at the near station ranged from 5 to 9 mph, while the speed reduction for trucks was 4 to 9 mph. The speed reduction at the near station cannot necessarily be attributed to an increased effectiveness of the flaggers after having received training. For Flagger 1, the decrease in speeds may be a result of an increased effectiveness of the flagger, or of a slower-moving traffic in the construction zone. For Flagger 2, the decrease in car and truck speeds after the

training session probably was a result of an increased effectiveness because of training. Analysis of field data indicates that training may not have the same effect on all flaggers.

For both flaggers, there was a decrease in the percentage of speeding vehicles as the vehicles approached the flagger, both before and after training.

This study served as a pilot study, evaluating only two flaggers in the same construction zone, with data being collected for a maximum of 6 hr for each flagger. Further studies should be made to evaluate the long-term effectiveness of flaggers after having received training, and should use a large number of flaggers in a variety of study sites. It cannot be said whether training flaggers will have the same effect on all flaggers, or whether or not training will improve the effectiveness of the flagger at all, as the flagger may not follow the instructions given to him in the training session. However, a more comprehensive training program may improve the effectiveness of training and the performance of the flagger.

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