Comparative Study of Advance Warning Signs at High Speed Signalized Intersections

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The effects of two dynamic signs that begin to flash a few seconds before the onset of the yellow interval and a static sign that flashes all the time were examined at rural, high-speed signalized intersections. The dynamic signs included (a) a PTSWF (prepare to stop when flashing) sign, and (b) an FSSA (flashing symbolic signal ahead) sign with green, yellow, and red circles. The static sign was a CFSSA (continuously flashing symbolic signal ahead) sign with the three circles. The effects of these signs on vehicular speeds at different segments of the intersection approach including the dilemma zone were analyzed as were the vehicle conflict rates and the responses from the drivers' surveys. The study revealed that the PTSWF and FSSA signs generally have similar effects on driver behavior. It is advantageous to consider the CFSSA sign before using the PTSWF sign because the PTSWF and FSSA signs have a few undesirable effects on vehicular speeds, unlike the CFSSA sign. The use of a PTSWF sign at a tangent approach to a high-speed signalized intersection is discouraged.

High-speed signalized intersections at unexpected or hidden locations generally pose a potentially hazardous situation for drivers when the signal indication changes from green to yellow. A dilemma or decision zone exists on the intersection approach upstream of the stopline, which makes it difficult for the drivers to decide whether to stop during the yellow interval or go through the intersection before the beginning of the red interval. Traffic engineers generally have used advance warning signs and inductive loop detectors to warn drivers of the existence of the signalized intersection or to adjust the green time to minimize dilemma zone problems.

This paper presents the final outcomes of a study in Ohio, the earlier results of which were previously published (*1*). The following advance warning signs with flashers were examined. The signs were ground mounted and diamond shaped.

SIGNS

Prepare To Stop When Flashing Sign

As indicated in Figure 1, the prepare to stop when flashing (PTSWF) sign has two flashers (one at the top and the other at the bottom) that begin to flash a few seconds before the onset of the yellow interval and continue to flash until the end of the red interval. Meanwhile the loop detectors, if any, are temporarily shut down until the beginning of the next green phase.

Currently, Ohio Department of Transportation (ODOT) uses a passive symbolic signal ahead (PSSA) sign in advance of the PTSWF sign at signalized intersections. The PSSA sign is a passive advance warning sign that has the green, red, and yellow circles. The purpose of installing a PSSA sign is to inform the drivers of the existence of the signalized intersection because the PTSWF sign is not necessarily capable of conveying this message.

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Flashing Symbolic Signal Ahead Sign

The flashing symbolic signal ahead (FSSA) sign is similar to the PTSWF sign except that the words are replaced by the green, red, and yellow circles. The two flashers operate in the same manner as the PTSWF sign.

Continuously Flashing Symbolic Signal Ahead Sign

The continuously flashing symbolic signal ahead (CFSSA) sign, as the name suggests, has flashers that flash all the time. The flashers are not connected to the signal controller.

The overall objective of the study was to perform a comparative evaluation of these signs relative to their effects on driver behavior. These signs were installed at high-speed signalized intersections in rural areas where signals are normally unexpected or hidden because of curvature.

STUDY DESIGN AND DATA COLLECTION

The study was performed by collecting traffic flow and related data at the following study sites.

Intersection with Tangent Approach: US-33 at US-127 in Mercer County

The study site is a two-lane highway located in a rural area. The PSSA sign was located at 397 m (1,303 ft) upstream of the intersection and the PTSWF sign (and later the FSSA or CFSSA sign) existed at 200 m (655 ft) upstream of the intersection. The signs at the study sites are listed in chronological order:

- 1988; PSSA sign with no flashers. This sign was used for reference purposes only.
- 1989–1991: PTSWF and PSSA signs,
- 1992: FSSA sign (Because the FSSA sign has the green, yellow, and red circles, the PSSA sign was removed from the site.), and
- 1993: CFSSA sign.

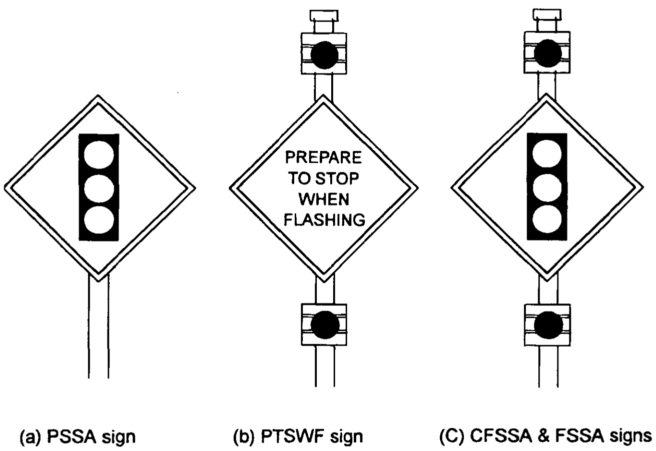

FIGURE 1 Advance warning signs with flashers.

Intersection with Curved Approach: SR-37 at US-40 in Licking County

The study site is a curved approach with one lane and no exclusive left turning lane at the intersection. In 1988, there was a CFSSA sign with only one flasher at 312 m (1,024 ft) upstream of the intersection. In 1989, it was replaced by a PSSA sign, and a PTSWF sign was installed at 202 m (664 ft) upstream of the intersection. In 1992, the PTSWF sign was replaced by an FSSA sign and the PSSA sign was removed. In 1993, a CFSSA sign with two flashers replaced the FSSA sign. The discussions below refer to the CFSSA sign installed in 1993. The following intersections were used as control sites: (a) intersection with tangent approach: US-36 and SR-235 in Champaign County; and (b) intersection with curved approach: US-127 and SR-725 in Preble County.

When a new sign was installed at an intersection, a minimum of 6 months was allowed for the drivers to become familiar with the sign before the data were collected. Because of time and financial constraints, it was not possible to counterbalance the order of the various treatments at the study sites. The driver learning effects, if any, could not be directly examined in this study.

The following data were collected at the study and control sites

Vehicle Speed

The intersection approach on which the data were collected was divided into the following four zones.

- Zone 1—The roadway segment in advance of the PSSA sign (US-33 at US-127) or the old CFSSA sign with one flasher (SR-37 at US-40);
- Zone 2—The roadway segment, downstream of Zone 1, measured from the existing sign to the PTSWF (or FSSA or CFSSA) sign;
- Zone 3—The roadway segment from the PTSWF (or FSSA or CFSSA) sign to the beginning of the decision zone;
- Zone 4—The roadway segment from the beginning of the decision zone to the stopline.

The data were collected by five observers who recorded the arrival time of sampled vehicles at various positions along the intersection approach. Other information recorded by the observers included vehicle type (passenger vehicles or trucks), flasher and signal indications when the vehicle arrived at selected positions, and whether the vehicle stopped at the intersection. The vehicles were sampled for several hours during various periods from 7:00 a.m. to midnight.

Vehicle Conflict

All vehicles moving through the intersection were observed for the following types of conflicts: (a) run red light, (b) stop abruptly, and (c) accelerate through yellow. The turning movements (through, right, or left turn) were also recorded.

Driver Survey

A questionnaire was prepared to obtain drivers' subjective responses to the advance warning signs. Copies of the questionnaire were mailed to area residents or distributed to visitors or employees at nearby business facilities.

A more detailed description of the method for data collection and the location of the signs appear elsewhere (*1*). The speed patterns were examined relative to the following conditions:

1. Flasher conditions (on or off) when the vehicles arrived at the locations of the existing sign as well as the PTSWF (or FSSA or CFSSA) sign, as applicable;
2. Signal indications (green, yellow, or red) when the vehicles arrived at the beginning of the decision zone and at the stopline; and
3. Vehicle status at the stopline (stop or go).

Vehicles were categorized according to several combinations of flasher and signal conditions and whether the vehicles stopped at the intersection, as follows:

1. Off-Off-Green-Green-Go,
2. Off-Off-Green-Yellow-Go,
3. On-Off-Green-Green-Go,
4. On-On-Red-Green-Go,
5. On-On-Red-Red-Stop, and
6. Off-On-Red-Red-Stop.

The first condition (off or on) refers to the status of the flashers when the vehicles arrived at the existing sign. Similarly, the second condition (off or on) refers to the status of the flashers when the vehicles arrived at the PTSWF (or FSSA or CFSSA) sign. The next two conditions (green-green, green-yellow, etc.) refer to the status of the signal indication when the vehicles arrived at the beginning of the dilemma zone and the stopline, respectively. The final condition (go or stop) refers to the status of the vehicle at the stopline, that is, whether the vehicle stopped.

STUDY RESULTS

Speed Study

The speed data were analyzed separately for the passenger vehicles and trucks in the through direction. The speed variables included in the analysis were the mean, 85th percentile, and 95th percentile speeds.

Condition: Off-Off-Green-Green-Go

Passenger Vehicles. When the PTSWF sign was installed on the tangent approach, the mean speeds in Zones 3 and 4 were almost equal (Figure 2). Similarly, when the FSSA sign existed on the tangent approach, the results indicated a similar speed pattern in Zones 3 and 4. However, when the CFSSA sign existed on the tangent approach, the mean speed in Zone 4 dropped by 11 kph (7 mph) from that in Zone 3. The result showed that the impacts of the dynamic (PTSWF or FSSA) and static (CFSSA) signs on the speed behavior of the drivers in Zone 4 were different. (The differences in mean speeds reported in this paper are based on *t*-tests at 0.05 level of significance.)

An analysis of the 85th percentile speeds demonstrated more noticeable changes in the speed patterns when the dynamic advance warning signs existed on the tangent approach. It showed that the PTSWF and FSSA signs caused an increase in the 85th percentile speeds in Zone 4, whereas the CFSSA sign caused a decrease. An analysis of the 95th percentile speed showed a similar speed pattern among the three signs.

The speed patterns on the curved approach are shown in Figure 3. The mean speed in zone 1 remained almost unchanged at 75 kph (47 mph) for the three signs, perhaps because of the existence of the roadway curvature. The difference between the mean speeds in Zones 3 and 4 was 10 and 11 kph (6 to 7 mph), with the speeds in Zone 4 being lower than that in Zone 3. Because it was a curved

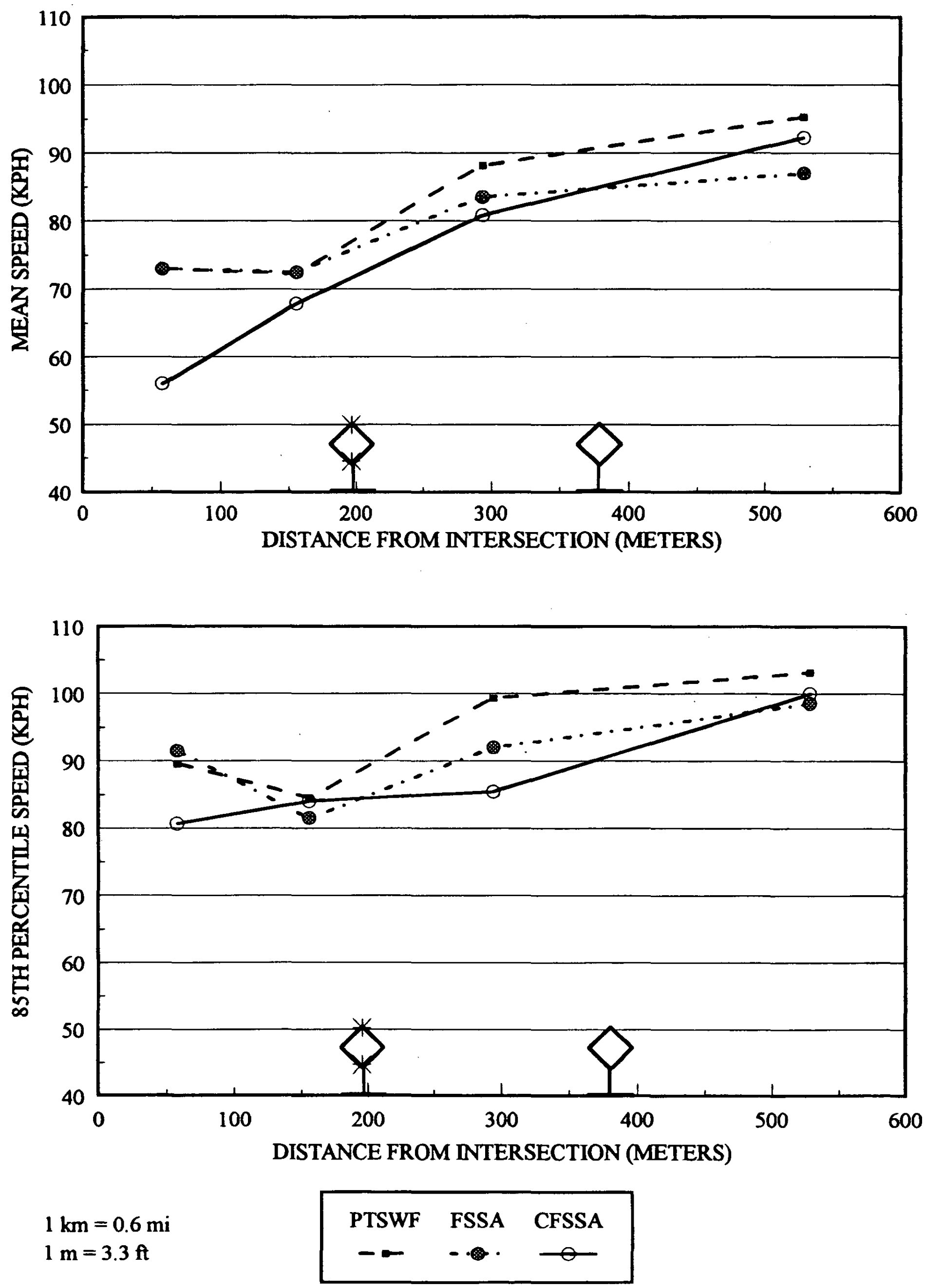

FIGURE 2 Speeds of passenger vehicles at tangent approach: Condition Off-Off-Green-Green-Go.

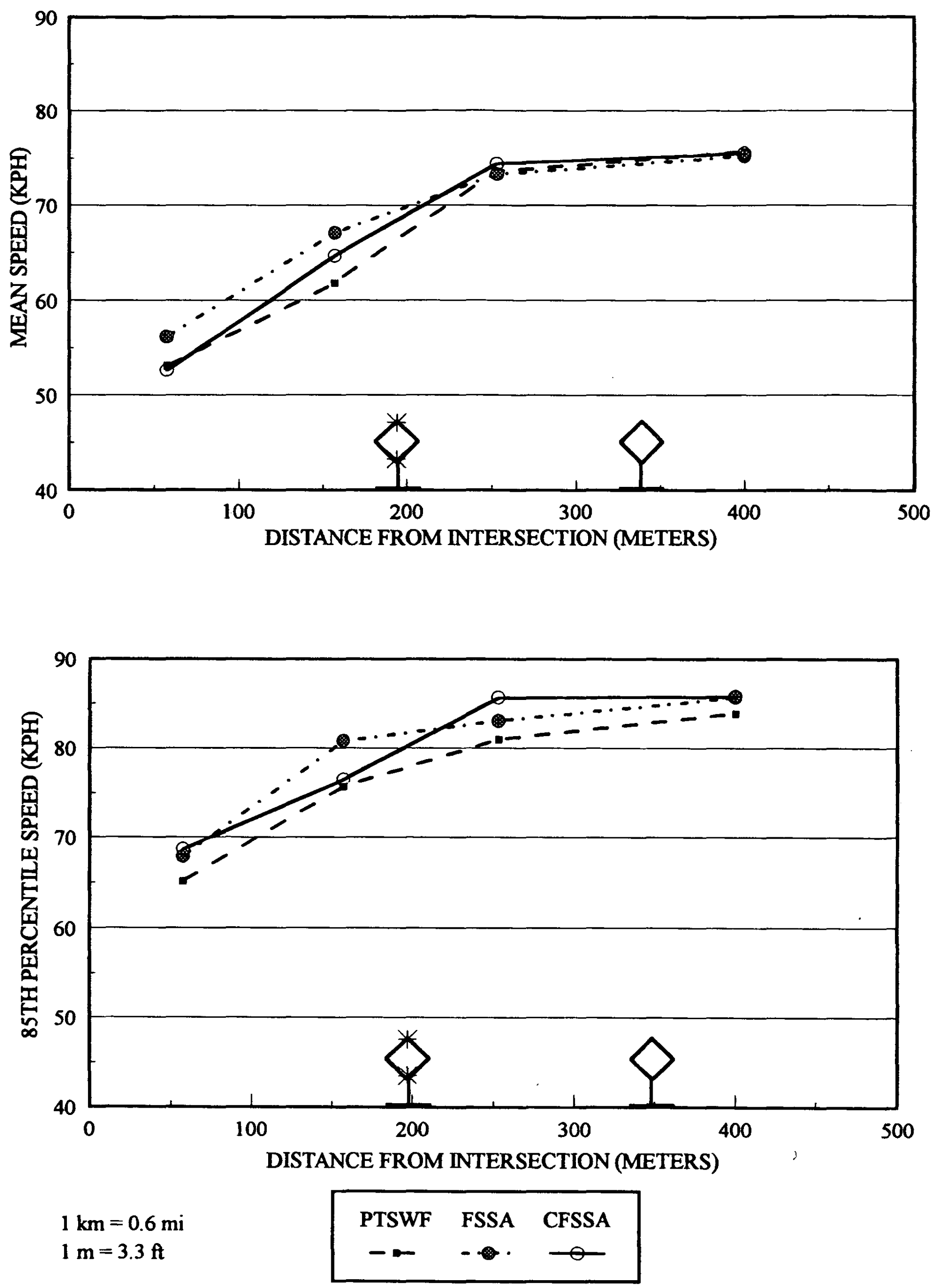

FIGURE 3 Speeds of passenger vehicles at curved approach: Condition Off-Off-Green-Green-Go.

approach, drivers were constrained on the selection of their speeds. The 85th and 95th percentile speeds also showed a diminishing pattern from Zone 1 to Zone 4. Overall, there was little difference on the speed pattern because of the existence of the PTSWF, FSSA, or CFSSA signs. The result is quite in contrast with that found in the tangent approach. It shows that roadway geometry is an important variable in the determination of the vehicular speeds as are flasher and signal indications.

Trucks. The speed data for trucks were separately analyzed (Figure 4). When the PTSWF sign existed on the tangent approach, the mean speeds in Zones 3 and 4 were almost equal. When the FSSA sign existed on the tangent approach, the trucks increased their mean speed by 5 kph (3 mph) when they traveled from Zone 3 to Zone 4. On the contrary, with the CFSSA sign on the tangent approach, the mean speeds in Zones 3 and 4 were almost equal.

The effects of the signs on vehicular speeds on the tangent approach were more noticeable when the data for the 85th percentile speeds were analyzed. When the PTSWF or FSSA sign existed on the tangent approach, the 85th percentile speeds increased when the trucks traveled from Zone 3 to Zone 4. On the other hand, there was no change in the 85th percentile speed in Zone 4 when the CFSSA sign existed on the tangent approach. The analysis of the 95th per-

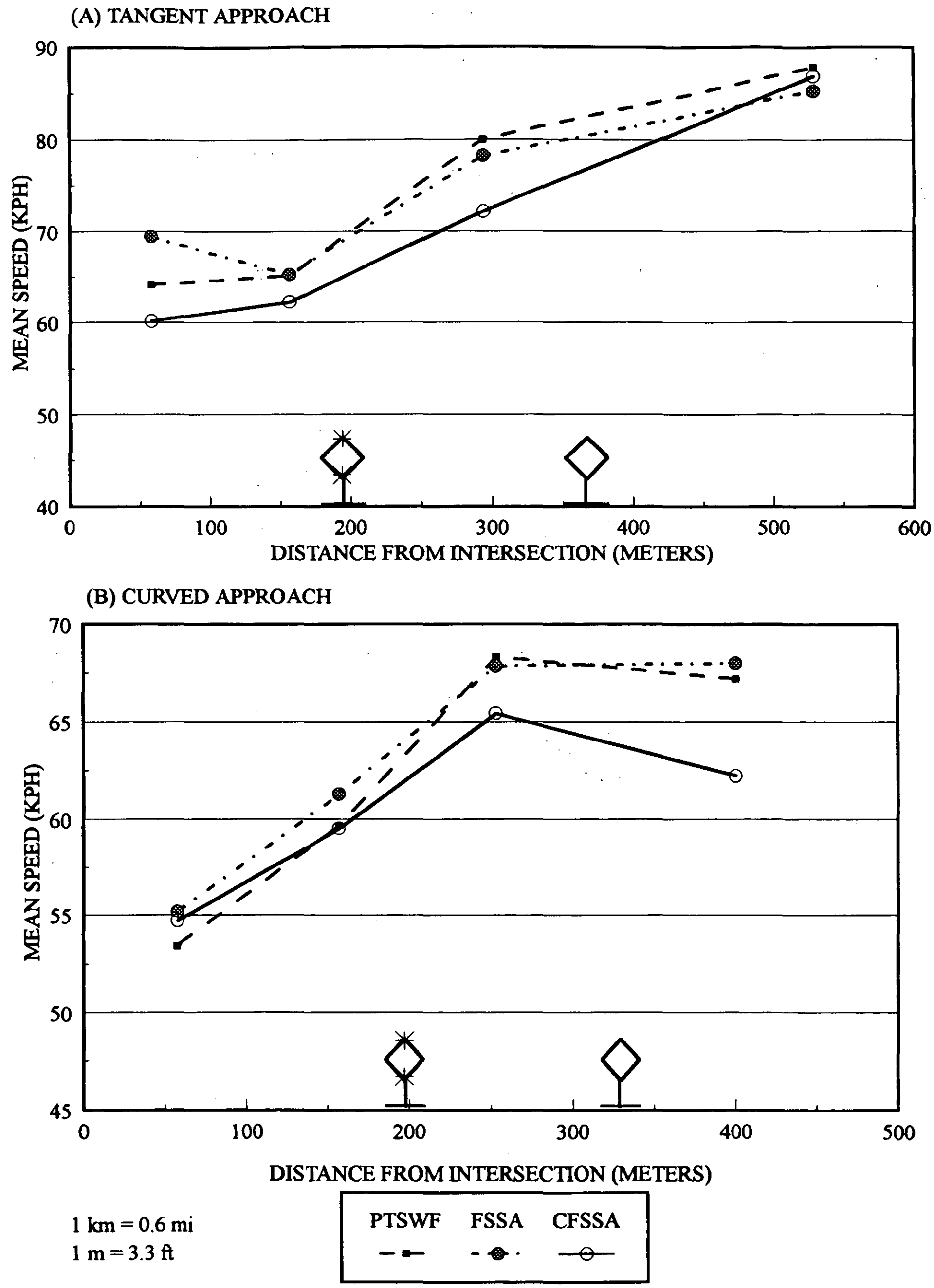

FIGURE 4 Speeds of passenger vehicles at tangent and curved approaches: Condition Off-Off-Green-Green-Go.

centile speeds of the trucks showed similar speed patterns on the approach.

The trucks on the curved approach showed a diminishing speed pattern as they traveled from Zone 1 to Zone 4 (Figure 4). Because the drivers were constrained by the roadway curvature on the selection of their speeds, there was no appreciable difference in their mean speeds in each zone when the PTSWF, FSSA, or CFSSA signs existed on the approach. The difference in the mean speeds between zones 3 and 4 was smaller (5 to 6 kph or 3 to 4 mph) for trucks than for the passenger vehicles (10 to 11 kph or 6 to 7 mph)

Condition: Off-Off-Green-Yellow-Go

Passenger Vehicles. Under the "off-off-green-yellow-go" condition, the signal indication changed from green to yellow when the vehicles traveled from the beginning of the decision zone to the stopline. When the PTSWF or FSSA sign existed on the tangent approach, the drivers of the passenger vehicles increased speed by 10 kph (6 mph) for the PTSWF sign and 6 kph (4 mph) for the FSSA sign when they traveled from Zone 3 to Zone 4 (Figure 5). On the contrary, a decrease of 7 mph in the mean speed was observed when

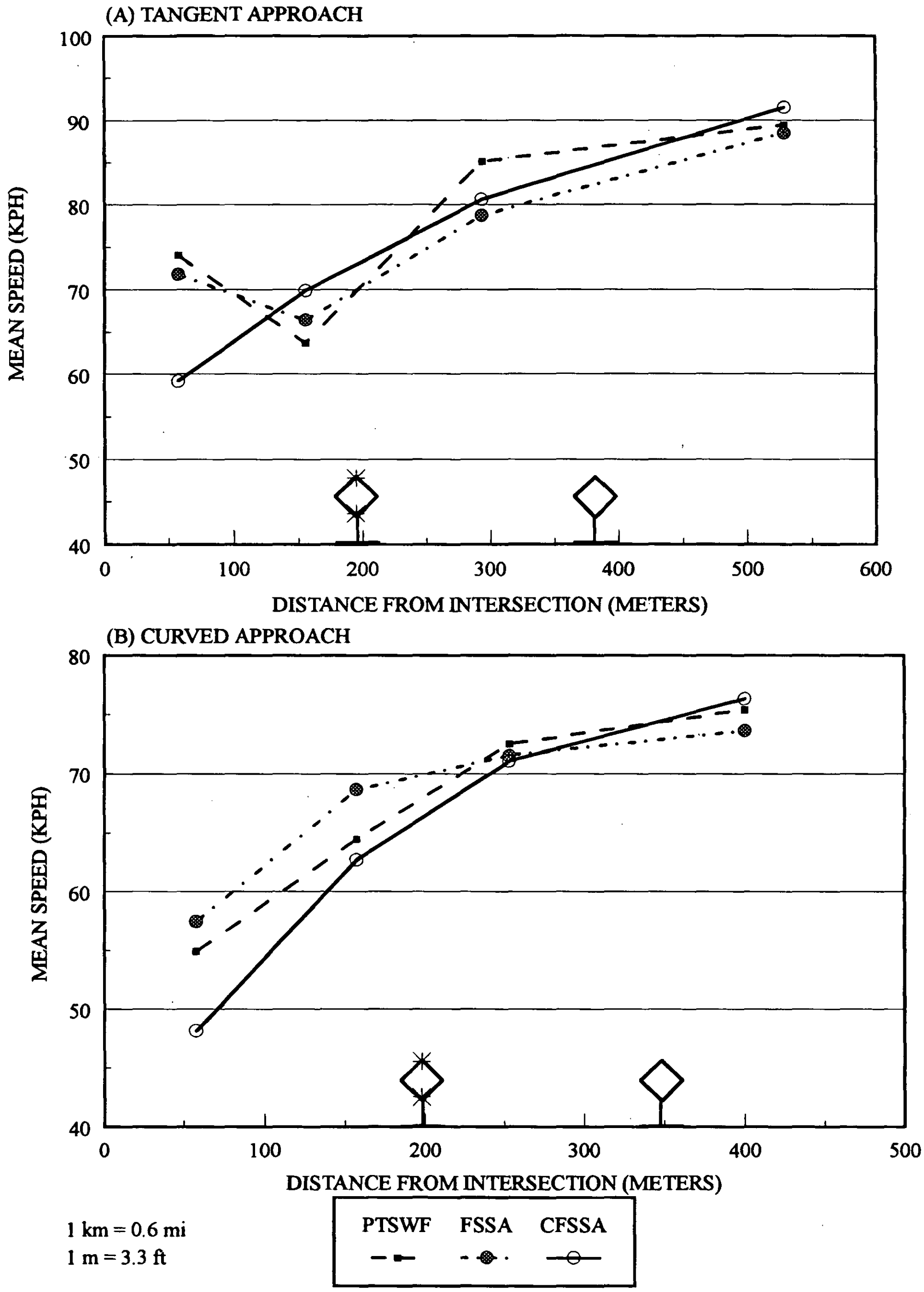

FIGURE 5 Speeds of passenger vehicles at tangent and curved approaches: Condition Off-Off-Green-Yellow-Go.

the CFSSA sign existed on the tangent approach. Although this result should be read with caution because of the small sample size, it indicates that the drivers were speeding up during the yellow interval when the PTSWF and FSSA signs existed on the tangent approach.

At the curved approach, the mean speeds in Zone 1 for the PTSWF, FSSA, or CFSSA signs indicated only a small difference because of the constraints caused by the roadway curvature (Figure 5). The speed showed a diminishing pattern when the vehicles traveled between Zone 1 and Zone 4. The result showed that the drivers drove through the curved intersection at a relatively lower speed when the CFSSA sign existed at the intersection. If reducing speed during the yellow interval is an objective of an advance warning sign, the CFSSA sign could be more effective than the PTSWF or FSSA sign.

Trucks. The results are not reported because of insufficient sample size.

Condition: On-On-Red-Red-Stop

Passenger Vehicles. The results showed that the mean speed in Zone 4 was the lowest for the PTSWF sign, indicating that the drivers reduced the speeds at a higher rate when the PTSWF sign existed on the curved approach. The 85th percentile speeds in Zone 4 were lower for the PTSWF and FSSA signs than for the CFSSA sign.

Trucks. The results for vehicular speeds at the curved approach indicated that the lowest mean speed in Zone 4 was associated with the PTSWF sign. A similar pattern was observed with the 85th percentile speeds. It showed that drivers could relate the flashers on the PTSWF sign with the likelihood of stopping at the intersection. Although the flashers on the FSSA sign operated in a manner similar to those on the PTSWF sign, the FSSA sign was less effective in reducing speed at the curved approach.

Other Conditions

The speed data for other flasher, signal, and stop conditions as previously listed were analyzed. However, no unusual speed patterns were found.

Conflict Analysis. The vehicle conflict data are indicated in Table 1. The total conflict rate for the PTSWF, FSSA, and CFSSA signs at the tangent approach varied between 28 and 34 conflicts per 1,000 vehicles. The number of vehicles running red lights were 2.4 per 1,000 vehicles for the PTSWF and FSSA signs and 4.7 per 1,000 vehicles for the CFSSA sign, indicating that the CFSSA sign had the highest rate of "running red light." It indicates that the PTSWF and FSSA signs were more effective in reducing the "running red light" problem than the CFSSA sign at the tangent approach.

No significant difference among the three signs in the number of vehicles speeding up on yellow light was found at the tangent approach. The number of vehicles with abrupt stop was slightly higher for the PTSWF sign.

The result of the vehicle conflict analysis at the curved approach showed that the CFSSA sign had the overall lowest conflict rate at 28 conflicts per 1,000 vehicles. However, the CFSSA sign also had the highest rate of vehicles running red light (4.7 per 1,000 vehicles). On the other hand, the CFSSA sign had the lowest number of vehicles (21 per 1,000 vehicles), speeding up during yellow interval. The number of vehicles making an abrupt stop was slightly higher (3.1 per 1,000 vehicles) for the PTSWF sign than for the CFSSA sign (2.4 for 1,000 vehicles).

TABLE 1 Vehicle Conflict Rates

			Conflicts Per 1000 Vehicles			
Intersection	Sign	Number of Vehicles	Run Red	Speed Up on Yellow	Abrupt Stop	Total
US 33 & US 127	PTSWF	1389	1.9	27.4	1.9	31.2
	FSSA	861	2.5	25.3	1.1	28.0
	CFSSA	1485	4.7	27.6	1.3	33.6
SR 37 & US 40	PTSWF	3737	2.4	31.6	3.1	37.2
	FSSA	1465	1.8	31.8	2.7	36.3
	CFSSA	1695	4.7	20.6	2.4	27.7

Driver Survey. During the survey performed in 1993, drivers were asked to indicate their preferences among the PTSWF, FSSA, and CFSSA signs. Among the 89 drivers who responded to the survey questionnaire concerning the signs at the tangent approach, almost half of them preferred the PTSWF sign. The percentage of respondents in favor of each sign was as follows: PTSWF, 48 percent; FSSA, 13 percent; CFSSA, 29 percent; and No preference, 10 percent.

Many respondents who preferred the PTSWF sign at the tangent approach indicated that the sign helped them to stop. Other respondents indicated that the CFSSA sign had little effect on local drivers because it was always flashing. One respondent indicated that the CFSSA sign would benefit out-of-state drivers. Although the FSSA sign operated in a manner similar to that of the PTSWF sign by activating the flashers a few seconds before the onset of the yellow interval, a large percentage of respondents preferred the PTSWF sign.

Similarly, of the 71 respondents who returned the questionnaire about signs on the curved approach, about two-thirds of the respondents preferred the PTSWF sign. The preferences of the respondents for the different signs were as follows: PTSWF, 65 percent; FSSA, 13 percent; CFSSA, 13 percent; and No preference, 9 percent.

The respondents indicated that the PTSWF sign helped them stop at the intersection or to learn in advance when the signal indication was going to change. They also indicated that the flasher on the CFSSA sign was likely to be ignored by local drivers because they knew it flashed all the time.

CONCLUSIONS AND RECOMMENDATIONS

The study revealed that the impacts of the PTSWF, FSSA, and CFSSA signs vary among intersections with tangent and curved approaches. It is evident that roadway geometry and flasher and signal indications are important parameters, based on which drivers adjust their speeds on an intersection approach. The PTSWF and FSSA signs are designed to prepare the drivers to stop, if necessary, at the intersection. However, the CFSSA sign, which is a static device, provides no clue about the possible state of signal indication or stop.

The study has shown that the PTSWF and FSSA signs generally have similar effects on driver behavior. The effects of the CFSSA sign generally resemble those of the PSSA sign, but the CFSSA sign has the added advantage of the flashers. Drivers in Ohio generally are familiar with the PTSWF sign because ODOT has been using it for several decades. The study did not find any advantage in replacing the PTSWF sign with the FSSA sign. Any use of the FSSA sign will require a long period of driver familiarization without any obvious operational benefit. If engineers are concerned that the PTSWF sign provides no prior information about the existence of the signal, the intersection can be equipped with a PSSA sign as in the study sites described before.

It seems advantageous to consider the CFSSA sign before using the PTSWF sign because the PTSWF and FSSA signs have a few undesirable effects on vehicular speeds. When flashers are off and the signal indication is green or yellow, drivers on an approach with PTSWF or FSSA sign generally increase their speeds in an apparent attempt "to beat the light." This behavior is particularly more evident on intersections with a tangent approach than on intersections with a curved approach because the roadway curvature provides restrictions to the drivers on the selection of their speeds. The effect of the CFSSA sign on vehicular speed is generally similar to that of the PSSA sign, which shows a diminishing pattern along the entire length of the intersection approach. The use of the CFSSA sign may also allow a more effective use of detection techniques to minimize dilemma zone problems.

At an intersection approach with a PTSWF sign, drivers generally increase speed when the flashers are inactive and the signal is green or yellow. At a curved approach, however, the PTSWF sign may help drivers reduce speed during a red interval.

On the basis of the findings of the study, the recommendations are listed below:

1. The PTSWF sign is preferable to the FSSA sign in Ohio. The FSSA sign should not be used as a replacement for the PTSWF sign.
2. At any potential location for an advance warning sign with flashers, the CFSSA sign should be considered for selection prior to the PTSWF sign.
3. The use of the PTSWF sign at a tangent approach to a high-speed signalized intersection is discouraged.

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