Active Advance Warning Signs at High-Speed Signalized Intersections: Results of a Study in Ohio

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The effectiveness of several active advance warning signs at high-speed signalized intersections in Ohio was evaluated. The signs included the Prepare To Stop When Flashing (PTSWF), Flashing Symbolic Signal Ahead (FSSA), Continuously Flashing Symbolic Signal Ahead (CFSSA), and Passive Symbolic Signal Ahead (PSSA) signs. The research was designed as a before and after study with control sites. The measures of effectiveness included vehicular speeds at various segments of the intersection approach, vehicle conflict rates, and ratings by drivers. The study found that the effects of the signs on drivers varied among intersections with tangent and curved approaches. The PTSWF or FSSA signs generally encouraged high speed when the flasher was inactive and the signal indication was either green or yellow. Fewer motorists related the PTSWF sign to the traffic signal. In general, active advance warning signs should be discouraged at high-speed signalized intersections, particularly at intersections with tangent approach. At high-speed signalized intersections with curved approach, the CFSSA sign seems to be preferable to the PTSWF sign for reducing speed. Further study to examine the possible use of the FSSA sign in providing a better alternative at locations where the PTSWF sign cannot be effective is recommended.

A high accident potential exists at high-speed signalized intersections where an area close to an intersection, called a decision or dilemma zone, often poses a problem to a driver in stopping safely during the yellow clearance or in proceeding through the intersection before the beginning of the red interval. Traditionally, state highway departments have used active advance warning signs such as the Prepare to Stop When Flashing, Red Signal Ahead, or Signal Ahead signs to inform the driver of the presence of a signal and the fact that it is red or about to turn red. Generally, the signs are activated near the end of the green interval and remain active until the end of the red interval. No specific standards exist, however, for the design, use, and operation of active advance warning signs at high-speed signalized intersections. The lack of a standard has made many agencies increasingly concerned about possible tort liability claims arising out of any ineffective traffic control systems.

The objective of this study was to examine the effectiveness of selected active advance warning signs at high-speed signalized intersections in Ohio. The signs included the Prepare to Stop When Flashing (PTSWF), Flashing Symbolic Signal Ahead (FSSA), Continuously Flashing Symbolic Signal Ahead (CFSSA), and Passive Symbolic Signal Ahead (PSSA) signs. The intersections were located on rural or suburban highways where signals are generally unexpected or hidden by curves.

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BACKGROUND

A survey of practicing traffic engineers by the West Virginia University found that the three most commonly used types of active advance warning devices were the flashing Red Signal Ahead sign, the PTSWF sign and its variations, and flashing strobe lights (*1*). A study by the Maryland Department of Transportation found that the Red Signal Ahead sign had the potential to be an effective device in reducing right angle accidents (*2,3*). However, the study to evaluate the effectiveness of the experimental flashing red strobe sign was inconclusive. A study by the Minnesota Department of Transportation assessed the use of and experience with advance warning devices through a survey of state traffic officials (*4*). Among the 39 states responding to the survey, 29 (74 percent) reported using some form of advance warning device at high-speed signalized intersections. The most common sign was the PTSWF sign or its variations. Also fairly common among these states were blank-out messages and W3-3 Signal Ahead signs with flashers activated for signal change intervals.

A Kentucky study suggested that the use of active advance warning signs should be considered at problem locations at which a large number of avoidable accidents have occurred (*5*). A study by FHWA examined driver responses to several active advance warning signs on the highway driving simulator (HYSIM) (*6*). Eight different signs were examined at two problem locations: intersections hidden by horizontal curves and unexpected intersections at rural highways. The signs included the following:

1. PTSWF [(a) ground mounted, diamond shaped, (b) overhead, diamond shaped, (c) ground mounted, rectangular shaped, and (d) overhead, rectangular shaped],
2. Flashing Red Signal Ahead,
3. FSSA,
4. Signal Ahead, and
5. PSSA.

The study indicated that the FSSA sign was the most desirable sign. The PTSWF sign was the most incorrectly identified sign. Driver preference for the PTSWF signs was in general the lowest among the signs.

Field validation of the HYSIM results is needed. The results of the HYSIM study are applicable only to nighttime driving, however, because subject drivers on the HYSIM were only exposed to nighttime driving.

In summary, the literature review showed that field studies were needed to examine the effects of active advance warning signs at high-speed signalized intersections. This paper presents the results of an evaluation of the effectiveness of several advance warning signs at high-speed signalized intersections in Ohio.

RESEARCH APPROACH

The study was performed by collecting and analyzing field data at several high-speed signalized intersections in Ohio. The following measures of effectiveness were utilized:

1. Vehicle speeds in advance of the warning sign, in advance of the decision zone, and in advance of the stop line;
2. Vehicle acceleration or speed change rate;
3. Vehicle conflict rate; and
4. Driver survey.

These measures are further discussed in the later sections.

The research was designed as a before and after study with control sites. Several geometric and traffic characteristics, including approach alignment, number of lanes, and posted speed limit, were used to select the control and study sites. However, accident rates were not examined because of the excessively long time (at least 3 years after the installation of a sign) that must elapse before any meaningful conclusion can be made from an analysis of accident data.

The following four types of ground-mounted, diamond-shaped advance warning signs were selected for the study (Figure 1):

1. PTSWF sign—The PTSWF sign is the most commonly used advanced warning sign at high-speed signalized intersections in Ohio.
2. FSSA sign—The FSSA sign was selected for the study because of the general trend in the nation toward using symbolic signs for traffic control and operations. This sign was never used in Ohio before.
3. CFSSA sign—In Ohio, the CFSSA sign is often used at intersections with curved approach.
4. PSSA sign—The PSSA is only the Signal Ahead sign and no flashers are used. It is the most commonly used sign at signalized intersections.

The PTSWF and FSSA signs had yellow flashers at top and bottom that were activated near the end of the green interval and remained active until the end of the red interval. The CFSSA sign had one to two flashers that were active all the time.

The intersections were divided into two categories: intersections with tangent approach and intersections with curved approach.

To control for the effects of external factors that were not accounted for by the study, the experiments were performed at three control sites (intersections) and four study sites. The

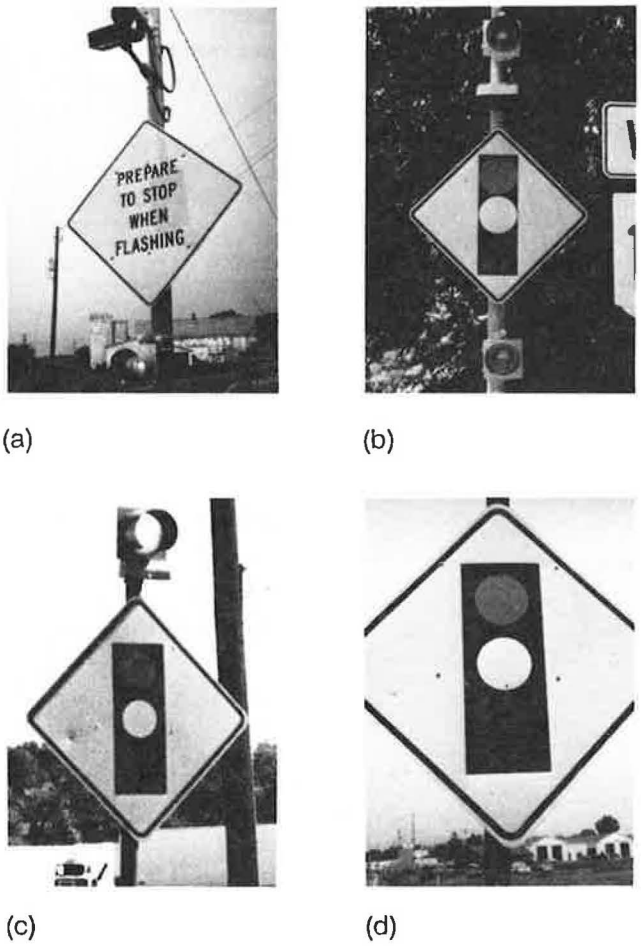


FIGURE 1 Advance warning signs: (*a*) PTSWF, (*b*) FSSA, (*c*) CFSSA, and (*d*) PSSA.

sites were so selected that the geometric conditions and posted speed limits at the control and study sites were similar. At the control sites, the advance warning signs consisted of a PSSA sign at intersections with tangent approach and a CFSSA sign at intersections with curved approach during both the before and after periods. At the study sites, the existing advance warning signs during the before period consisted of the same type of signs as those at the control sites. After the necessary data were collected during the before period, the Ohio Department of Transportation installed PTSWF or FSSA signs at the study sites. A minimum of 6 months were allowed for the motorists to become familiar with the new signs before the data for the after period were collected. The PTSWF sign was tested on two-lane highways and the FSSA sign on both two-lane and four-lane divided highways.

DATA COLLECTION

Each intersection approach was divided into three segments (called "zones" in the following discussions) as follows:

1. Zone 1 is the segment of the intersection approach just upstream of the advance warning sign.

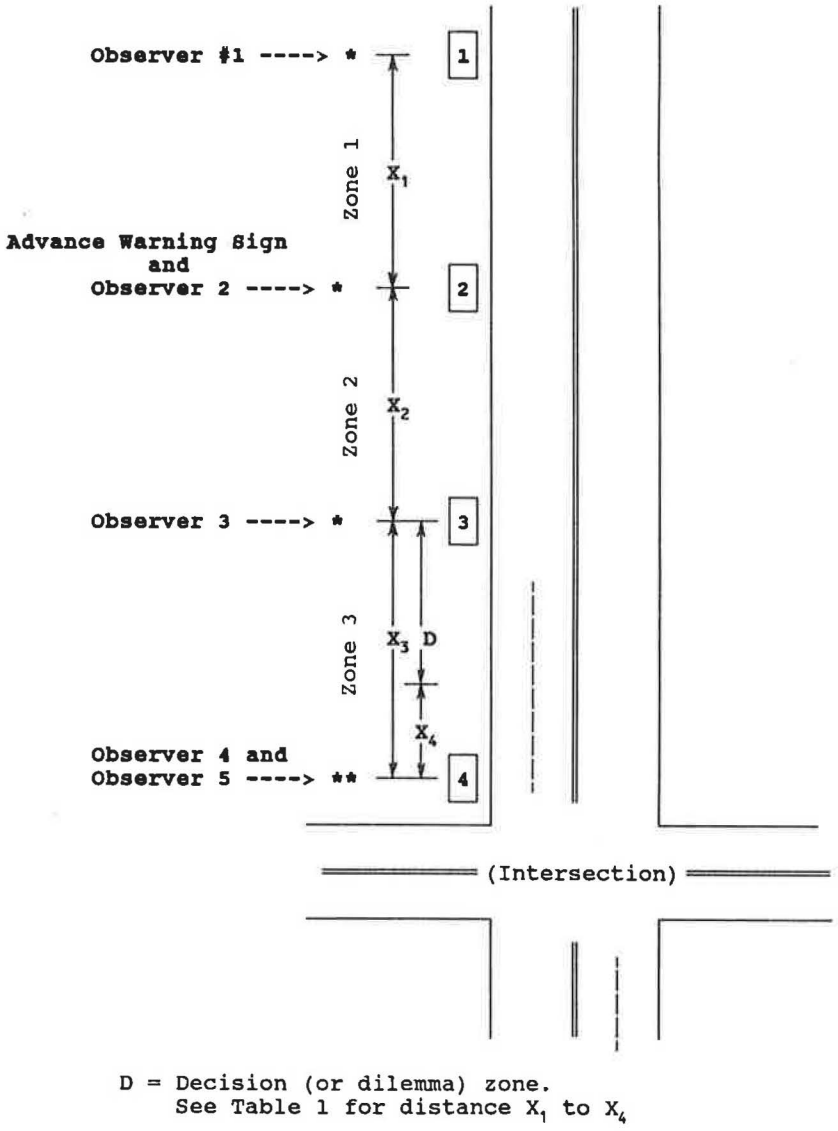


FIGURE 2 Data collection with three speed zones.

2. Zone 2 is the segment of the intersection approach just past the advance warning sign but in advance of the decision zone.

3. Zone 3 is the final segment of the intersection approach, measured from the beginning of the decision zone to the stopline.

A schematic representation of the three speed zones is shown in Figure 2. The boundaries of the decision zones (*7*) and the locations of observers for data collection are shown in Table 1.

At the study intersections where a PTSWF sign was installed during the after period, a PSSA sign existed at an upstream location [as per the Ohio Department of Transportation's (ODOT's) current practice]. Hence an additional speed zone called Zone 4 (see Figure 3) was used for collecting the data at these intersections.

A total of five or six observers manually collected the data at each intersection. The observers carried a previously syn-

TABLE 1 Location of Observers

INTERSECTION	X_1 (ft)	X_2 (ft)	X_3 (ft)	X_4 (ft)	X_5 (ft)
SR 37 at US 40	640 (640)[a]	640 (280)	384 (384)	233 (233)	NA[b] (360)
US 33 at US 127	919 (919)	919 (271)	384 (384)	233 (233)	NA (648)
SR 126 at Loveland-Madeira Rd	360	360	325	150	NA
SR 4 at Liberty-Fairfield Rd	918	918	384	233	NA
SR 36 at SR 235	615	615	384	233	NA
US 127 at SR 725	911	911	351	170	NA
US 68 at Moorfield Rd	436	436	384	233	NA

[a]*Values in parentheses are for "after" period*
[b]*Not applicable*

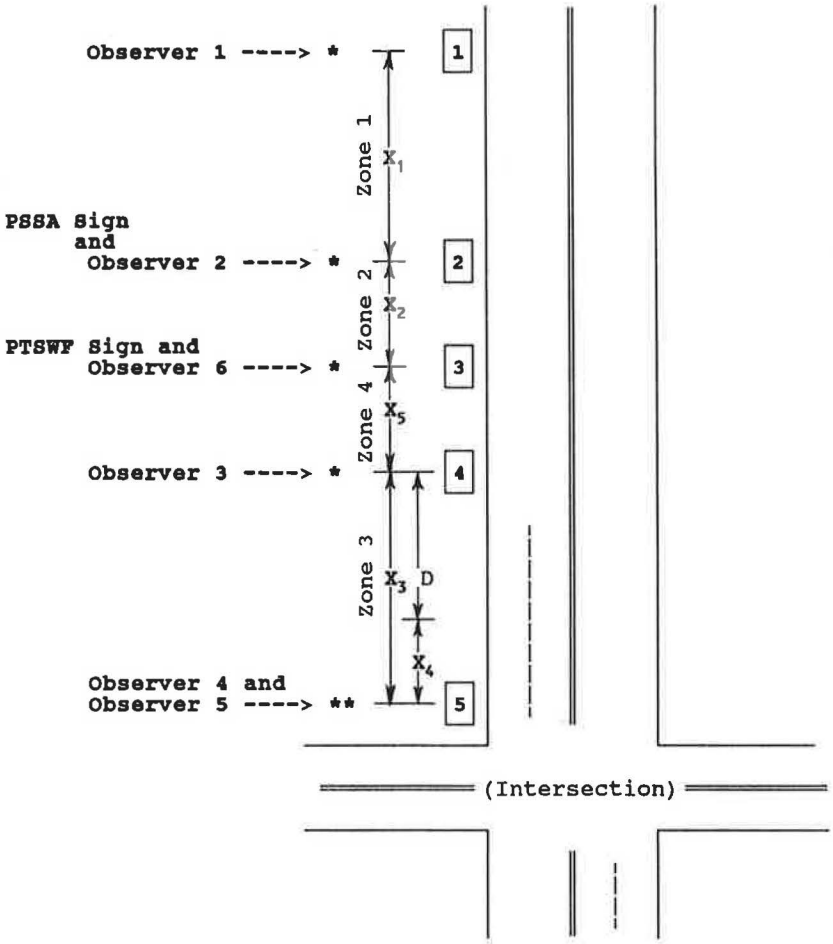


FIGURE 3 Data collection with four speed zones.

chronized electronic stop watch with an accuracy of 1/100 sec. and a walkie-talkie for communication with each other. A previous study has shown that speed measurement techniques using stop watches are capable of yielding individual speed measurements to an accuracy of 1 mph (*9*). Observer 1 randomly selected the vehicles (Figures 2 and 3). If vehicles arrived as a platoon, the first vehicle was sampled. Upon receiving command from Observer 1, the remaining observers located at the respective positions closely recorded the vehicle's movement until it crossed the intersection. The following information for each vehicle was recorded:

1. Time of arrival of the vehicle at Positions 1 to 5;
2. Vehicle type—Light vehicle (passenger car, van, and pickup) or heavy vehicle (truck, bus, and recreational vehicle);
3. Flasher Indication 1—If the approach had a sign with a flasher, whether the flasher was active when the vehicle arrived at the CFSSA or FSSA sign, or at the PSSA sign if the approach had a PTSWF sign;
4. Flasher Indication 2—Whether the flasher was active when the vehicle arrived at the PTSWF sign;
5. Signal Indication 1—Traffic signal indication when the vehicle entered into the decision zone;
6. Signal Indication 2—Traffic signal indication when the vehicle reached the stopline;
7. Stop—Whether the vehicle proceeded through the intersection or stopped;
8. Conflict—The following type of conflicts (*8*) were recorded:
   a. Run red light—A proceeding vehicle was upstream of the stopline when the signal turned red;
   b. Abrupt stop—A driver decided at the last instant to stop; the deceleration, particularly within 100 ft of the stopline, caused the front end of the vehicle to dip noticeably;
   c. Acceleration through yellow—The driver "guns" the engine to clear the intersection; and
9. Direction—Through, left turn, or right turn.

The speed sampling periods were 7:00–9:00 a.m., 10:00–11:30 a.m., 1:00–2:30 p.m., 3:00–6:00 p.m., 9:00 p.m.–midnight.

Driver Survey

A questionnaire was prepared to obtain drivers' subjective responses to the advance warning signs. Several techniques, including personal interview, mailing, and distribution of the questionnaire to employees of nearby business facilities, were employed. The information obtained from the respondents included the following:

1. Driver characteristics—age, sex, education, driving experience, familiarity with site;
2. What the sign meant to the respondent;
3. What action the respondent took when he/she saw the sign;
4. Respondent's action (if any) when the traffic signal turned yellow;
5. Respondent's ratings of the sign on a scale of 0 to 10 based on adequacy of information, of time available to read and understand message, of ease with which message is read and understood, and overall effectiveness.

The average sample size per location was about 50.

Traffic Volume

Traffic volume is not a measure of effectiveness. It is related, however, to vehicle conflict rate at the intersection. The traffic volume at the intersection, categorized by light and heavy vehicles, was manually recorded.

DATA ANALYSIS AND RESULTS

The data were used to calculate the mean vehicular speed in each zone. In general, when vehicles traveled from Zone 1 to Zone 3 in an intersection approach, the mean speed was gradually reduced until the vehicles crossed the intersection. The magnitude of the speed reduction seemed to be related to the geometric condition, type of advance warning sign, flasher indication (if applicable), and signal indication. Acceleration and deceleration rates between adjacent zones were calculated and compared with standard rates (*10*) that motorists are expected to conform to when they are not required to react rapidly. An acceleration or deceleration rate in excess of the standard rate may indicate a potential problem for the motorists at the intersection. The analysis showed that none of the acceleration or deceleration rates observed during the before and after periods exceeded the standard rate.

To test the null hypothesis that there was no difference in speed change rate during the before and after periods, *t*-tests were performed at 0.05 level of significance. The alternate hypothesis stated that there existed a difference in speed change rate. For a meaningful test, the effects caused by the difference in original speed should be eliminated. For example, if the speed of a vehicle changed from 60 mph to 30 mph, and the speed of another vehicle changed from 30 to 15 mph over the same distance, the net difference is 30 mph for the former and 15 mph for the latter. But the speed change rate is the same for both vehicles, because speed change rate = (60 − 30)/60 = .05 or (30 − 15)/30 = 0.5. The effect of the difference in original speed was eliminated by performing *t*-tests on speeds in which the logarithm of speed, instead of absolute speed, was employed. Thus, speed difference = log(speed 1) − log(speed 2). Hence for the two vehicles in the above example, log(speed 1) − log(speed 2) = log(60/30) or log (30/15) = log(2). The results of the *t*-test for which the speed change rates were found significant are discussed in the respective sections below.

A sample of the before and after speed data for the intersection on US-33 at US-127 is presented in Tables 2 and 3. The mean speeds of passenger cars for different signal con-

TABLE 2 Mean Speed on US-33 at US-127 During "Before" Period

Speed Zone	Signal1[a]	Signal2[b]	Proceed[c]	Speed (MPH)	Acceleration (ft/s/s)
1	Green	Green	Yes	54.9	-0.54
2	Green	Green	Yes	50.5	-1.85
3	Green	Green	Yes	37.8	
1	Green	Yellow	Yes	61.8	-1.21
2	Green	Yellow	Yes	52.8	-2.80
3	Green	Yellow	Yes	33.0	
1	Green	Red	No	57.4	-1.67
2	Green	Red	No	43.2	-2.50
3	Green	Red	No	18.7	-1.96
1	Yellow	Red	No	58.5	-0.91
2	Yellow	Red	No	51.4	-3.54
3	Yellow	Red	No	22.3	-2.79
1	Red	Green	Yes	58.1	-1.19
2	Red	Green	Yes	48.6	-2.83
3	Red	Green	Yes	25.4	
1	Red	Red	No	58.4	-1.00
2	Red	Red	No	50.6	-3.41
3	Red	Red	No	22.2	-2.76

[a]*Signal indication when a vehicle arrives at the "decision zone"*
[b]*Signal indication when the vehicle arrives at the stop line*
[c]*Does vehicle proceed through the intersection without stopping?*

TABLE 3 Mean Speed on US-33 at US-127 During "After" Period

Speed Zone	Flasher 1[a]	Flasher 2[b]	Signal 1[c]	Signal 2[d]	Proceed Intersection[e]	Speed (MPH)	Acceleration (ft/s/s)
1	Inact.	Inact.	Green	Green	Yes	60.9	-0.89
2	Inact.	Inact.	Green	Green	Yes	55.3	-2.29
3	Inact.	Inact.	Green	Green	Yes	45.6	0.18
4	Inact.	Inact.	Green	Green	Yes	46.2	
1	Inact.	Inact.	Green	Yellow	Yes	58.1	-0.65
2	Inact.	Inact.	Green	Yellow	Yes	53.9	-2.96
3	Inact.	Inact.	Green	Yellow	Yes	40.5	1.53
4	Inact.	Inact.	Green	Yellow	Yes	45.9	
1	Inact.	Active	Red	Red	No	55.6	-0.11
2	Inact.	Active	Red	Red	No	54.9	-2.69
3	Inact.	Active	Red	Red	No	43.2	-4.35
4	Inact.	Active	Red	Red	No	23.3	-3.04
1	Active	Inact.	Green	Green	Yes	57.2	-0.75
2	Active	Inact.	Green	Green	Yes	52.2	-2.21
3	Active	Inact.	Green	Green	Yes	42.2	-0.88
4	Active	Inact.	Green	Green	Yes	38.9	
1	Active	Active	Red	Red	No	59.0	-0.81
2	Active	Active	Red	Red	No	53.8	-2.47
3	Active	Active	Red	Red	No	42.9	-4.14
4	Active	Active	Red	Red	No	24.1	-3.25

[a]*Signal indication when the vehicle arrives at the "decision zone".*
[b]*Signal indication when the vehicle arrives at the stop line.*
[c]*Flasher indication when the vehicle arrives at the PSSA sign.*
[d]*Flasher indication when the vehicle arrives at the PTSWF sign.*
[e]*Does vehicle proceed through the intersection without stopping?*

ditions were plotted graphically. Samples of the graphs are presented in Figures 4 and 5. Data for other sites could not be included in this paper for space reasons.

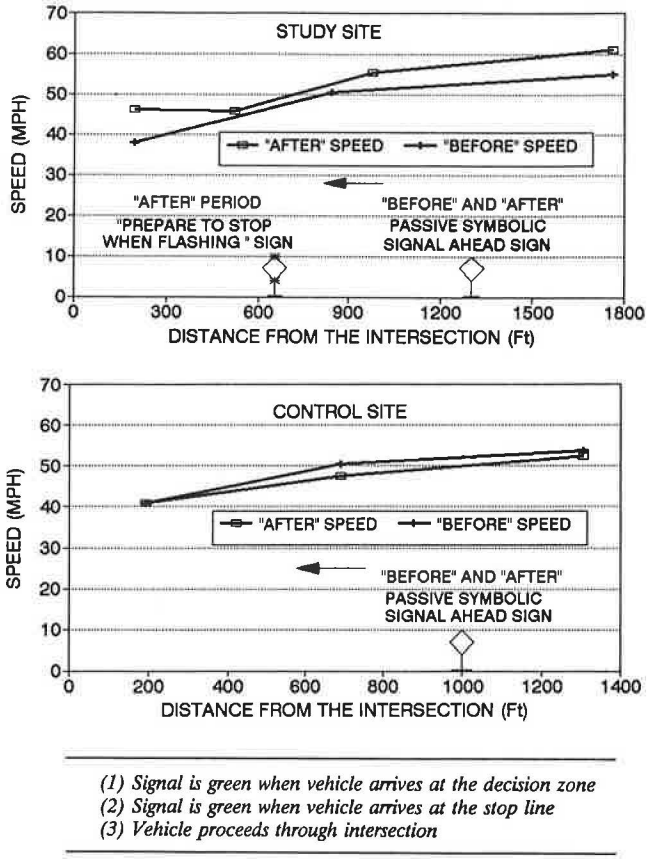
EFFECTS OF PTSWF SIGN

The effects of the PTSWF sign seemed to vary among intersections with tangent and curved approaches.

PTSWF Sign at Tangent Approach

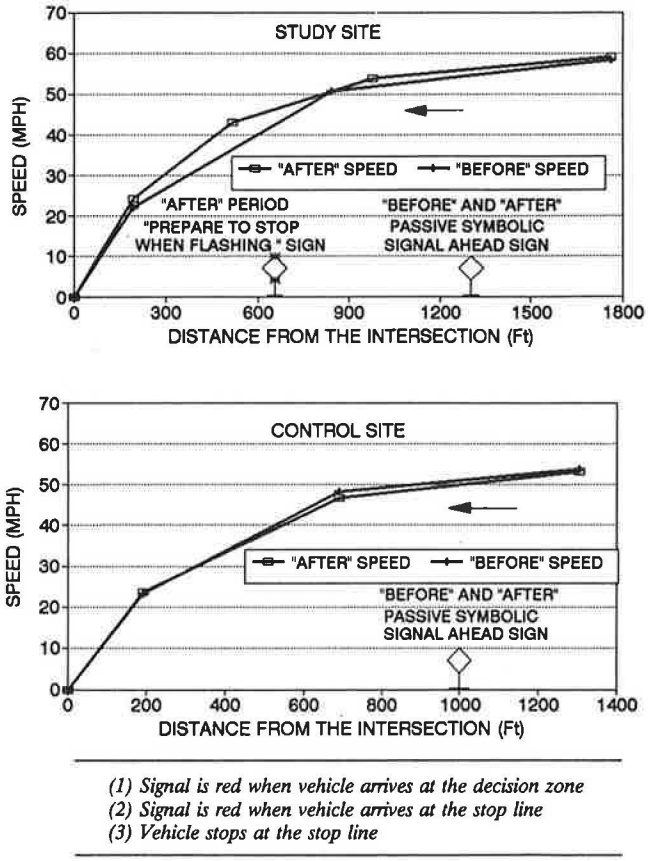
A PSSA sign existed at the intersection approach during both periods. In addition, during the after period, a PTSWF sign existed at a downstream location on the intersection approach. As shown in Figure 3, four zones were used for calculating speed during the after period, as compared to three zones during the before period. The result showed that mean speeds were particularly influenced by the condition of the flasher on the PTSWF sign when vehicles arrived at the PSSA and PTSWF signs. When the flasher was inactive during the time of vehicle arrivals at the PSSA and PTSWF signs and the signal was green when vehicles arrived at the stopline, the mean speeds in Zone 1 and Zone 3 increased by 6 and 8 mph, respectively, indicating a substantial increase in mean speeds on the intersection approach during the after period. The *t*-test showed that the speed change rate in Zone 3 was significant at the 5 percent level of significance. In contrast, the mean speeds changed little at the control site during the same period. Contrary to the normal pattern typically observed at signalized intersections, mean speed in Zone 3 was higher than in Zone 2 during the green interval, indicating that motorists were speeding up when they arrived in the decision zone. This is not a desirable trend, especially if the speed increase is great, because it is likely to create a difficult situation for motorists taking any corrective or evasive action that becomes necessary. This trend was not observed during the before period when only the PSSA sign existed at the intersection approach.

Additionally, when the flasher was inactive during the time of vehicle arrivals at the PSSA and PTSWF signs, an undesirable trend was observed among vehicles proceeding through the intersection during the yellow interval. For example, the mean speed in Zone 1 was observed to be 58 mph, which decreased to 41 mph in the next zone but increased to 46 mph in Zone 3. During the *t*-test, the speed change rate was found to be significant at a 5 percent level of significance. The speed increase in Zone 3 is contrary to normal expectations, indicating that motorists were speeding up in the yellow interval during the after period. Again, this type of trend was not observed at the intersection during the before period.



(1) Signal is green when vehicle arrives at the decision zone
(2) Signal is green when vehicle arrives at the stop line
(3) Vehicle proceeds through intersection

FIGURE 4 Mean speed on study site and control site (condition: green-green-proceed).



(1) Signal is red when vehicle arrives at the decision zone
(2) Signal is red when vehicle arrives at the stop line
(3) Vehicle stops at the stop line

FIGURE 5 Mean speed on study site and control site (condition: red-red-stop).

The speed pattern was different when the flasher was active during the time of vehicle arrivals at the PSSA sign and inactive at the PTSWF sign. There was no appreciable increase in the mean speeds before the motorists crossed the intersection. It seemed that motorists understood the information received from the flasher and proceeded through the intersection without increasing speed.

The study site had a conflict rate of 82 conflicts per 1,000 vehicles during the before period that was reduced to 31 conflicts per 1,000 vehicles (or by 62 percent) after the installation and operation of the PTSWF sign (Table 4). However, the control site that had 27 conflicts per 1,000 vehicles during the before period also experienced a 62 percent decrease (to 10 conflicts per 1,000 vehicles) during the after period. Hence, the conflict reduction at the study site cannot be attributed to the PTSWF sign.

When motorists were surveyed about the PSSA sign during the before period, 90 percent of the respondents indicated that the sign means, "There is a signal ahead" (Table 5). During the after period, however, only 60 percent of the respondents related the PTSWF sign with the signal. This result supports the findings of the FHWA study on the HYSIM in which drivers commented that the PTSWF sign had a limited and inadequate relationship to a traffic signal. However at this site, an overwhelming proportion of the respondents had favorable comments about the PTSWF sign because many area residents were concerned with the relatively high percentage of trucks on the highway. In response to the statement, "Overall, the sign was helpful to me in terms of my driving through or stopping at the intersection," on a scale of 0 to 10 the rating increased from 7.6 for the PSSA sign to 8.6 for the PTSWF sign.

PTSWF Sign at Curved Approach

During the before period, a CFSSA sign existed at the intersection approach. During the after period, the CFSSA sign was converted to a PSSA sign, and a PTSWF sign was installed at a downstream location at the intersection approach as per ODOT's current practice. When the flasher was inactive during the time of vehicle arrivals at the PSSA and PTSWF signs, and the signal was green when vehicles reached the stopline, no appreciable difference in mean speeds between the two periods was found. The *t*-test showed that the speed change rate was not significant at the 5 percent level of significance. This result is in sharp contrast with the previously described intersection with tangent approach where the mean speeds were found to increase by 6 to 8 mph. It indicated that the effects of the PTSWF sign vary between intersections with tangent and curved approaches.

An important change in speed pattern, similar to the pattern observed at the tangent approach, was observed when vehicles proceeded through the intersection during the yellow interval. The speed in Zone 3 increased by 7 mph for vehicles that had reached the PSSA and PTSWF signs when the flasher was inactive. The *t*-test showed that the speed change rate was significant at the 5 percent level of significance. It seemed that when the light turned yellow, motorists were either unable or unwilling to reduce speed or stop at the intersection. The increase in speed may not be desirable, especially at an intersection approach with curvature. If reducing speed at the intersection during yellow interval is an objective of the advance warning sign, the PTSWF sign is less effective than the CFSSA sign.

The analysis showed that the vehicle conflict rate had increased by 15 percent during the after period. Considering that the conflict rate at the control site had declined by 36 percent during the same period, the real increase in conflict rate at the study site is larger than the 15 percent rate observed at the intersection.

The result of the driver survey showed that the PTSWF sign received a rating of 8.1–8.7 on a scale of 0 to 10, in contrast to the ratings of 6.8–7.2 for the CFSSA sign, indicating that motorists generally preferred the PTSWF sign to the CFSSA sign. However, in response to the question, "What does the sign mean to you?," fewer motorists seemed to relate the PTSWF sign to the traffic signal, because the percentage of motorists who thought the PTSWF sign meant there was a traffic signal ahead dropped from 76 percent during the before period to 60 percent during the after period. The number of motorists who indicated they slow down when they see the sign increased from 56 percent during the before period to 70 percent during the after period.

TABLE 4 Traffic Volume and Vehicle Conflict Rates[a]

INTERSECTION	TOTAL TRAFFIC[b] (VEH)	RUN RED	SPEED UP ON YELLOW	ABRUPT STOP	TOTAL CONFLICT
SR 36 "BEFORE"	868	2.3	23.0	1.5	26.8
SR 36 "AFTER"	905	1.1	9.1	0.0	10.2
CHANGE[c]	-4.3%	2.2%	60.4%	100%	61.9%
SR 33 "BEFORE"	719	8.5	66.6	7.0	82.1
SR 33 "AFTER"	594	1.7	28.0	1.8	31.5
CHANGE	17.4 %	80.0%	58.0%	74.3%	61.6%

[a] *Vehicle conflicts are expressed per 1000 vehicles*
[b] *Traffic volume during 11 hour period*
[c] *Change = (Before's - After's)/Before's*

EFFECTS OF FSSA SIGN

As with the PTSWF sign, the effects of the FSSA sign seemed to vary among intersections with tangent and curved approaches.

FSSA Sign at Curved Approach on Two-Lane Highway

During the before period, two CFSSA signs were at the intersection approach (one on each side of the roadway) that were replaced by an FSSA sign during the after period. The result showed that the mean speed in Zone 3 remained unchanged during the after period, indicating no difference in the effects of the two signs.

TABLE 5 Driver Survey

US 33 AT US 127	Average (before)	Average (after)	Comparison[a]
HOW OFTEN DO YOU DRIVE ON THE HIGHWAY ?			
About once a day	13 %	20 %	-58 %
More than once a day	58 %	36 %	38 %
About once or twice a week	25 %	33 %	-33 %
About once or twice a month	4 %	10 %	-159 %
WHAT DOES THE SIGN MEAN TO YOU ?			
There is a signal ahead	90 %	60 %	32 %
Slow down	46 %	52 %	13 %
Be ready to stop if necessary	67 %	84 %	25 %
Does not mean any thing	0 %	0 %	0 %
Others	4 %	2 %	50 %
WHAT ACTION DO YOU TAKE WHEN YOU SEE THE SIGN ?			
Slow down	73 %	80 %	10 %
Become alert	75 %	63 %	16 %
Do nothing until I see the traffic light	4 %	2 %	50 %
Others	4 %	2 %	50 %
DO YOU TAKE ANY ACTION WHEN LIGHT TURNS YELLOW ?			
Try to stop	50 %	50 %	0 %
Speed up to enter intersection before red	4 %	2 %	50 %
Depends on how close I am to the intersection	54 %	58 %	- 7 %
Others	8 %	6 %	25 %
RATINGS[b]			
Sign Adequately Alerts Me to Stop or Drive Through	7.46 (3.97)[c]	8.63 (1.92)	-16 %
Time Adequate to Read or Understand Message	7.85 (3.36)	8.78 (1.21)	-12 %
The Ease with Which Message Is Read	7.75 (4.35)	8.74 (1.23)	-13 %
Overall, The Sign Was Helpful	7.66 (5.05)	8.61 (2.32)	-11 %
AGE 1=(<20),2=(20-29),3=(30-39),4=(40-49) 5=(50-59),6=(60-69),7=(70 and above)	4.8	4.9	-3 %
SEX Male	81 %	78 %	4 %
Female	19 %	22 %	-16 %
DRIVING EXPERIENCE 1=(<1), 2=(1-2), 3=(3-5), 4=(6-10), 5=(>10)	4.8	5.0	- 3 %
MILES DRIVEN/YEAR 1=(<5000), 2=(5000-10000), 3=(>10000)	2.6	2.5	5 %
LAST SCHOOL GRADE ATTENDED (1-17)	12.5	12.5	0 %
VISION			
Not wear glasses or other lenses	37 %	39 %	-5 %
Wear lasses	23 %	28 %	-22 %
Wear bifocals	15 %	35 %	133 %
Wear contact lenses	4 %	11 %	175 %
Sample Size	49	46	6 %

[a]*Comparison = (before's - after's)/(before's) x 100%*
[b]*Rating on 0-10 scale*
[c]*Number in parentheses represents standard deviation*

When the signal indication was red and vehicles stopped at the intersection, mean speeds in Zone 3 decreased by 4 mph during the after period. The *t*-test found the speed change rate to be significant at the 5 percent level of significance. Drivers seemed to understand that, when the FSSA sign was active, the signal was likely to remain red when they reached the intersection. On the other hand, the CFSSA sign provided no advance information to the drivers about possible signal indication upon arrival at the intersection.

The results showed that the vehicle conflict rate had declined by 8 percent (from 31 conflicts per 1,000 vehicles during the before period to 29 conflicts during the after period). But the control site had experienced a 36 percent reduction in vehicle conflict (from 42 conflicts per 1,000 vehicles to 26 conflicts) during the same period. Hence the FSSA sign did not seem to be effective in reducing vehicle conflict.

The result of the driver survey showed that few differences in the ratings for the CFSSA and FSSA signs. In response to some specific questions during the after period, 46 percent more respondents seemed to understand that the sign meant, "There is a signal ahead," 48 percent more indicated it meant, "Slow down," and 80 percent more indicated they would "become alert" when they saw the sign. Overall, drivers' responses to the FSSA sign were positive.

FSSA Sign at Tangent Approach on Four-Lane Divided Highway

During the before period, two PSSA signs were posted, one on each side of the roadway. For the after period, these signs were removed and replaced by two FSSA signs at a downstream location on the intersection approach. In general, when the flasher was inactive and the signal indication was green, the mean speeds in the three zones were generally 2 to 4 mph higher during the after period. When the flasher was active, and the signal was red, the mean speed of vehicles was 4 to 7 mph higher at the upstream zone, which narrowed down to 0.5 to 2 mph in Zone 3. The result showed that motorists reduced speed only after they passed the FSSA sign, indicating that the location of the FSSA sign had an important impact on speed before motorists stopped at the intersection.

The analysis showed little difference in vehicle conflict rates during the two periods. The result of the driver survey showed that the overall rating of the FSSA sign was slightly higher than that of the PSSA sign. Two important changes in drivers' responses were noted during the after period. First, 85 percent of the respondents indicated that the FSSA sign meant "be ready to stop if necessary," which is in sharp contrast to the 21 percent of respondents who had the same opinion about the PSSA sign. Second, respondents who indicated that they slowed down when they saw the sign increased from 23 percent to 50 percent. However, for unexplained reasons, 20 percent fewer respondents indicated the sign means, "There is a signal ahead."

CONCLUSIONS AND RECOMMENDATIONS

The results of this study should be used with caution because the study was conducted on a limited number of sites. The conclusions and recommendations are as follows:

1. An increase of speed at an intersection approach, particularly in the decision zone or its vicinity at a high-speed signalized intersection, is not desirable for safe movements of vehicles through the intersection. Hence, in general, the use of active advance warning signs such as the PTSWF or FSSA signs should be discouraged. The signs were found to encourage high speed under some flasher and signal conditions, particularly when the flasher was inactive and the signal indication was either green or yellow. The signs should be particularly discouraged at high-speed signalized intersections with a tangent approach.
2. At high-speed signalized intersections with a curved approach, the CFSSA sign seems to be preferable to the PTSWF sign for reducing speed. The PTSWF sign at a curved approach seemed to encourage high speed during the yellow interval and also increased the vehicle conflict rate. Fewer motorists related the PTSWF sign to the traffic signal at high-speed signalized intersections.
3. A study to further investigate the effectiveness of the FSSA sign at high-speed signalized intersections is recommended. Although the FSSA sign did not seem to be effective in reducing the vehicle conflict rate at curved approach, it seemed to assist motorists to prepare for stopping at the intersection when the flasher was active and the signal was red. The possibility that the FSSA sign provides a better alternative at locations where the PTSWF sign cannot be effective should be examined.
4. Future study should examine the effects of the active advance warning signs on frequency and severity of accidents at high-speed signalized intersections. Finally, the current practice of locating and timing an active warning sign at high-speed signalized intersections should be reviewed.

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REFERENCES

1. R. N. Eck. Active Advance Warning Signs at High-Speed Signalized Intersections: A Survey of Practice. In *Transportation Research Record 1010*, TRB, National Research Council, Washington, D.C., 1985.
2. W. J. Styles. *Evaluation of the Flashing Red Signal Ahead Sign.* Report FHWA/MD-83/06, HS-038 678. Maryland Department of Transportation, FHWA, U.S. Department of Transportation, June 1982.
3. W. J. Styles. *Evaluation of the Flashing Red Strobe Signal.* Report FHWA/MD-83/07, HS-038 679. Maryland Department of Transportation, FHWA, U.S. Department of Transportation, June 1982.
4. Minnesota Department of Transportation. *Evaluation of Dynamic Signing Used to Alert Motorists to Traffic Signal Change Interval.* Technical Memorandum No. 07043-185, Feb. 1985.
5. K. R. Agent. Traffic Control and Accidents at Rural High-Speed Intersections. In *Transportation Research Record 1160*, TRB, National Research Council, Washington, D.C., 1988.
6. Z. A. Sabra. *Driver Response to Active Advance Warning Signs at High-Speed Signalized Intersections.* Report FHWA/RD-86/130. FHWA, U.S. Department of Transportation, Oct. 1985.
7. P. S. Parsonson. Signalization of High-Speed, Isolated Intersections. In *Transportation Research Record 681*. TRB, National Research Council, Washington, D.C., 1978.
8. P. S. Parsonson, R. A. Day, J. A. Gawlas, and G. W. Black. Use of EC-DC Detector for Signalization of High-Speed Intersections. In *Transportation Research Record 737*. TRB, National Research Council, Washington, D.C., 1979.
9. F. R. Hanscom. *Effectiveness of Changeable Message Displays in Advance of High-Speed Freeway Lane Closure.* Report 235. National Cooperative Highway Research Program, TRB, National Research Council, Washington, D.C., 1981.
10. R. F. Benkohal and J. Treiterer. CARSIM: Car-Following Model for Simulation of Traffic in Normal and Stop-and-Go Conditions. In *Transportation Research Record 1194*, TRB, National Research Council, Washington, D.C., 1988.

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