TRAFFIC CONTROL FOR MAINTENANCE ON HIGH-SPEED HIGHWAYS

by

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ABSTRACT

Observations were first made at lane closures on interstate highways where yellow warning signs were erected routinely in conjunction with contract work. Later data provided direct comparison between new yellow and new orange signs. One sign scheme was used throughout the study. Driver obedience improved when new signs of either color were used; this finding implies that signs should always be maintained in good condition. Orange signs were slightly more effective than yellow signs in reducing traffic conflicts and merges near the traffic cones. Results of the study tend to support the adoption of orange as the standard color for signing construction and maintenance sites. However, differences between the two colors were rather small. Driver preference polls supported the orange signs more strongly. A degree of driver insensitivity toward signing was shown. In general, variables such as short sight distances, high volumes, poor condition of signs, and driver insensitivity produced unsafe situations at lane closures. However, the scope of the study did not permit observations at sufficient sites and(or) at sufficient times to serve as a definitive exploration of such variables as weather, terrain, vertical and horizontal alignment, or level of service.

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Offered for publication to the
Highway Research Board

December 1973

INTRODUCTION

Maintenance work which requires barricading one or more lanes of a high-speed roadway creates a potential hazard to the unwary traveler and to the worker. The problem is twofold: first, the proper messages must be presented to the approaching driver far enough in advance to allow him time to decelerate and merge before reaching the actual work site; and second, the driver must obey the messages.

Standards for temporary signing have been rather difficult to develop and implement. Even well-prepared standards do not supplant judgement, discretion, and ingenuity in specific instances. Effective signing and barricading will surely cause a minimum of interference with the flow of traffic. A lane closure where all lanes operate at capacity during peak hours cannot operate effectively unless some of the traffic is diverted onto alternate routes. Public announcements and advice to travelers have proven to be helpful in managing these situations.

This study was concerned only with left and right lane closures; shoulder closures and other maintenance activities were not observed. All data were taken during favorable weather conditions. The scope of the study did not permit observations at sufficient sites and(or) at sufficient times to serve as a definitive exploration of such variables as weather, terrain, vertical and horizontal alignment, or level of service. It was inevitable that data from the several sites be combined for purposes of comparison, even though different circumstances existed at most sites. The possibility of signing a "dummy" maintenance site was rejected from the outset of the study due to the unnecessary risks created for motorists and consequent liabilities.

PROCEDURE

During the summer of 1971, safety improvements were made on I 75 in Scott and Grant Counties and on I 64 between Frankfort and Louisville, Kentucky. Research personnel were able to observe and collect data at various lane closures. Cooperation of the contractors was excellent.

In Phase 1, observations were made at sites signed by contractors. In Phase 2, contractors' signs were replaced with new yellow signs and then with new orange signs. Phase 2 also included observation of the new signs at sites where other research activities required lane closures. Phase 2 provided direct comparison between yellow and orange signs. The new yellow signs were hung over the contractors' signs (Figure 1); traffic was observed for one hour; then new orange signs were superposed; and observations continued for another hour. Care was taken to position signs according to the scheme shown in Figure 2. At all times, observers attempted to be inconspicuous to the motorists. Tables 1 through 4 summarize these data indicated below.

SPOT SPEEDS

Radar spot speeds were taken at the first sign (2500-ft (760-m) sign) and again at the first traffic cone (see Figure 2). Walkie-talkies were used by the forward radar meter operator to relay identification of each vehicle to the second meter operator.

TRAFFIC CONFLICTS

Traffic conflicts were categorized and defined as follows:

Abnormal Brake Application -- A very rapid deceleration causing "dipping" of vehicle's front end (tire squealing noted separately).

Forced Merge – A vehicle changing lanes directly in front of a following vehicle, causing the following vehicle to apply its brakes; first vehicle forces-in, risking possible contact.

Complete Stop – Driver waits too long to merge and is forced to come to a stop and wait for a gap.

MERGING MANEUVERS

Observers were able to record the location of merging maneuvers to the nearest hundred feet (30 meters). For consistency of observation, the point of merging was considered to be where the left front tire crossed the centerline stripe when merging to the left and where the right front tire crossed the centerline stripe for merging to the right. These observations were later grouped according to percentages occurring in 500-ft (150-m) intervals.

TURN SIGNALS

Turn signals were counted and converted into percent of total lane changes.

FINDINGS

SPOT SPEEDS

Tables 5 and 6 show the mean speeds and mean decreases in speeds. The contractors' signs (Phase 1) were the least effective; drivers did not decrease speed as much and were therefore less obedient to the contractors' signs than they were to new signs. There was no significant difference in driver obedience toward the new yellow and new orange signs. Thus, the color of the signs had very little effect on speed. This is shown graphically in Figure 3. In general, other graphs not included here were similar. The total effect is attributed to differences in quality or condition of the signs. Indeed the condition of the contractors' signs was inferior to the new signs shown in Figure 4. Unfortunately, such signs are usually not adequately maintained if the construction or maintenance continues in time and if the same signs are moved from one place to another.

Auto speeds at the first cone (Table 5) were approximately 6 to 10 mph (2 to 4 m/s) higher than the advisory speed limit, that is, 45 mph (20 m/s), posted 500 ft (150 m) before the first cone. The mean 85th-percentile speed of all cars at the first cone was a little over 59 mph (26 m/s). Table 7 shows all mean 85th-percentile speeds.

TRAFFIC CONFLICTS

Figures 5 and 6 show conflicts per hundred vehicles at each site (Phase 2) for right and left lane closures, respectively. With volume effects excluded and everything else constant, it appears that orange signs involved fewer conflicts than yellow signs. When conflicts at sites signed by contractors were included in the analysis (Table 8), there was a statistically significant increase in the number of conflicts at right lane closures. At left lane closures, only orange signs were significantly lower. Here again, new orange signs were associated with fewer conflicts than new yellow signs, but this difference was not statistically significant. Signs used in Phase 2 yielded greater consistency of results; and according to Hurst, Perchonok, and Seguin *(1)*, greater consistency in these statistics indicates less driver confusion.

Most of the conflicts (about 87 percent) occurred within the half of the signed area nearest the cones. The most frequently recorded conflicts were abnormal brake applications.

MERGING MANEUVERS

Merging maneuvers were difficult to analyze because driver behavior and predisposition are so

integrally involved. Ideally, if motorists were adequately warned in advance of a lane closure, there would be relatively few merges within the last few hundred feet (meters) approaching the barricade. Adequate warning enables a driver to choose his own gap rather than be forced into the through lane at the last second. Fewer merges near the cones complement the safety of the work crew and flagman as well as the motorist. However, as traffic volume increases and as gaps become smaller, more and more drivers will be trapped in the closed lane -- thereby delaying otherwise normal merging and very likely causing an increase in forced merging. Also, there are always some drivers who will stay in the closed lane longer than they should just to pass one to two more cars -- that is to say, the more aggresive driver might remain in the closed lane to take advantage of the reduced lane volume at the cost of encountering higher risk when he ultimately changes lanes *(2)*. Consequently, where traffic is not congested, those drivers who deliberately disobey the messages and those who are not attentive may account for most of the merging within the last 500 ft (150 m) approaching the barricade. Indeed, dangers increased at those sites where the merging in this last 500 ft (150 m) was unusually high (see Tables 1 through 4). In general, those sites were complicated by short sight distances, high volumes, or poor traffic control; but no one factor was consistently dominant. For example, in Phase 2 there were five instances wherein more than 20 percent of all merges occurred within 500 ft (150 m) of the barricade. The hourly volumes varied from 188 to 757; sight distances ranged between 0.2 and 0.8 mile (0.4 and 1.5 kilometers); percent trucks varied from 9.5 to 28.7; the lengths of the sites were generally about 2500 ft (760 m), but one was 5000 ft (1525 m) in length; and various design features were included. It may be of interest to note that yellow signs were in use during four of the periods of observation, whereas orange signs were used during only one. Table 9 shows again that new signs are an improvement over the contractors' signs. Orange signs seem to be slightly superior to yellow signs in Phase 2 but not to a statistically significant extent.

Various frequency distributions were obtained by plotting distances (measured from the first cone) against the percent of merges occurring at each distance. There were peaks in these distributions at or near the 1000-ft (300-m) sign and near the first sign (2500 ft (760 m)). Some distributions showed three peaks. No explanation for these behavioral modes is offered here, but some interesting possibilities may be found in the work by Roberts, Hutchinson, and Carlson *(3)* on high, intermediate, and low expressive self-testers (risk takers). At sites where both sign colors were used, the two distributions roughly followed the same pattern (Figures 7 through 9). Orange signs sometimes reduced the number of merges nearer the cones and, therefore, in some cases tended to skew the distribution slightly more to the right (see Figures 10 through 12).

TURN SIGNAL INDICATIONS

Table 10 shows the mean number of turn signal indications for the various sites. The smaller percentages of turn signal actuations in Phase 2 may merely indicate the superior quality of the signs. There was no significant difference in turn signal usage with respect to yellow and orange signs in Phase 2.

DRIVER INTERVIEWS

A total of 62 drivers were interviewed after they had passed through a lane closure. Sign colors were alternated (2500-ft (760-m) and 1000-ft (300-m) signs were yellow; 1500-ft (460-m) and 500-ft (150-m) signs were orange) so drivers could make comparisons. Of course, total recall would be most unlikely. The questions and replies are shown in Table 11. Of the 62 people interviewed, 38 (61 percent) noticed two different colored warning signs. Of the 38 who noticed two colors, 27 (71 percent) said orange was more effective. This is assuming the four people who said red was more effective were actually referring to the orange signs. Ten people responded to Question 6 with one or more complaints. The most common complaint (given six times) was that there was not enough prior notice or advance warning. Two complaints were against flagmen. Others, each occurring once, were: signs are spread out too much, flashing arrow should be nearer the beginning of the cones, and signs are often in place when no lane closure or maintenance is in progress. This last complaint could account for the fact that in Question 8 almost 20 percent of the people interviewed said they wait until they see the actual lane blocked before merging.

DISCUSSION

No one factor was consistently responsible for undesirable conditions at the lane closures examined. High incidences of traffic conflicts and last-second merges were generally attributed to 1) short sight distances, 2) high volumes, 3) poor quality signs, and 4) driver insensitivity.

Adoption of the new AASHO Manual on Uniform Traffic Control Devices *(4)* provides for the first time a standard scheme for signing single-lane closures on interstate highways. The manual specifies the use of orange signs at construction and maintenance sites. Results of this study tend to substantiate the change in color.

An example of deceptive signing is depicted in Figure 13. These signs literally say there is road construction XXX feet (YYY meters) ahead. However, this distance is actually measured to the beginning of a project or to the white "Your Highway Taxes at Work" sign, and thus convey a false message

to the road user since there may be no construction visible for several miles (kilometers). This may cause a driver to doubt the validity of or to unconsciously disregard the next set of warning signs at an actual lane closure. The "Road Construction Next XX Miles (YY Kilometers)" sign (Figure 13), or several signs to this effect, would be adequate for the beginning of an extensive project. On several occasions during the course of this study, research personnel noticed warning signs in place but no maintenance or lane closure ahead. This practice also creates disrespect for maintenance signs. Such signs should be neatly covered or removed when work is suspended.

Other common errors in traffic control were observed during the data collection. Adjusting sign placement, i.e., lengthening distances between signs and between signs and cones, to compensate for poor sight distances is practical only to a certain extent. If the distances indicated by the signs are not within reason, drivers may tend to disbelieve the messages. Cone placement can be used to compensate for short sight distances. At one site (R 1.7), the contractor positioned a flashing arrow on the downhill side of a hill, and it did not come into view until the driver reached the crest of the hill. This accounted for the large number (45) of traffic conflicts recorded at that site.

The situation presented in Figure 14 could prove confusing. The overlay message had become unfastened on one side and presented an ambiguous choice as to where the construction actually was. It is a foregone conclusion that such errors must be avoided if safety and respect for warning signs are to be improved.

Since the new **Manual on Uniform Traffic Control** Devices (1971) specifies the use of orange signs for construction and maintenance sites, a distinction has been made from the standard, stationary, yellow warning signs (Merging Traffic, Fallen Rock Zone, Bridges Freeze Before Roadway, etc.) in more common use on highways. The new manual should also create a higher degree of uniformity in traffic control at lane closures. However, it is the responsibility of field personnel to enforce the standards and to insure the signs are highly legible.

Perhaps the most astonishing finding from this research issued from the driver interviews. Approximately 20 percent admitted or confessed they deliberately delayed merging. This is willful disobedience and may be related to a driver attitude which results in speeds 5 to 10 mph (2 to 4 m/s) greater than posted limits. Unfortunately, the conflict involvement rate of these drivers was not determined specifically and separately when field observations and interviews were conducted.

CONCLUSIONS

1. Orange signs produced a slight improvement over yellow signs in reducing traffic conflicts and merges

near the barricade.

2. New signs of either color produced a significant improvement over signs of lesser quality. Presumably signs maintained in a like-new condition, or nearly so, would suffice as well.
3. Driver attitudes toward lane-closure signs appear to have compounded and confounded the total problem of effective signing. Other, more daring innovations may be needed. Temporary rumble strips, chatter bars, or other disquieting devices may be necessary to adequately impress the message on some drivers.

REFERENCES

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3. Roberts, J. M., Hutchinson, J. W., and Carlson, G. S., *Traffic Control Devices and Self-Testing Values: A Preliminary Note,* **Traffic Engineering,** August 1972.

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TABLE 1

DATA FOR RIGHT-LANE CLOSURES
PHASE 1

			DATA SET NUMBERS								
			R 1.1	R 1.2	R 1.3	R 1.4	R 1.5	R 1.6	R 1.7	R 1.8	R 1.9
Sign Color			YELLOW	YELLOW	YELLOW	YELLOW	YELLOW	YELLOW	YELLOW	YELLOW	YELLOW
Volumes	Cars		271	261	616	395	374	578	509	421	540
	Trucks		67	86	64	85	59	54	67	88	68
	Total		338	347	680	480	433	632	576	509	608
Sight Distances to	First Sign	(miles)	0.25	0.85	0.60	0.65	0.65	0.50	0.50	0.30	0.40
		(kilometers)	0.40	1.37	0.97	1.05	1.05	0.80	0.80	0.48	0.64
	Flashing Arrow	(miles)				1.15	0.30	0.40	0.25	0.55	0.70
		(kilometers)				1.85	0.48	0.64	0.40	0.89	1.13
Design Elements –	Grade		-	+	+	+	Level	+	+	- to +	Level
	Curve		Lt	Tan	Rt	Tan	Rt	Rt	Tan	Rt to Tan	Tan
Mean Speeds At First Sign	Cars	(mph)	64.6	62.7	66.7	67.5	64.5	66.2	66.0	70.4	67.2
		(m/s)	28.9	28.0	29.8	30.2	28.8	29.6	29.5	31.5	30.0
	Trucks	(mph)	57.4	58.6	50.3	66.9	52.4	60.2	60.5	65.1	60.0
		(m/s)	25.7	26.2	22.5	29.9	23.4	26.9	27.0	29.1	26.8
Mean Speeds At First Cone	Cars	(mph)	52.0	51.9	52.8	54.5	56.4	55.1	55.4	59.0	53.4
		(m/s)	23.2	23.2	23.6	24.4	25.2	24.6	24.8	26.4	23.9
	Trucks	(mph)	53.3	49.9	42.5	56.5	50.6	46.9	49.0	54.7	50.2
		(m/s)	23.8	22.3	19.0	25.3	22.6	21.0	21.9	24.5	22.4
Decrease	Cars	(mph)	12.6	10.8	13.9	13.0	8.1	11.1	10.6	11.4	13.8
		(m/s)	5.7	4.8	6.2	5.8	3.6	5.0	4.7	5.1	6.1
	Trucks	(mph)	4.1	8.7	7.8	10.4	1.8	13.3	11.5	10.4	9.8
		(m/s)	1.9	3.9	3.5	4.6	0.8	5.9	5.1	4.6	4.4
Conflicts	Abnormal Braking		2	16	44	14	32	18	28	14	10
	Forced Merges		1	3	21	9	15	15	16	5	3
	Complete Stops		1	0	0	0	0	0	1	0	0
	Total		4	19	65	23	47	33	45	19	13
Turn Signals			44	46	91	68	63	108	98	95	75
Percent Merges with Turn Signals			16.9	20.9	20.9	23.1	20.3	27.8	25.4	26.0	27.8
Distance between First Sign and First Cone		(ft)	2200	1970	1925	2600	2085	1825	2000	2958	2430
		(meters)	670	600	586	792	636	556	610	902	741
Percent Merges Occurring within*	0 - 500 ft (0 - 152 m)		25.7	9.6	46.8	12.9	36.0	14.4	31.6	9.2	5.6
	501 - 1000 ft (153 - 304 m)		17.6	28.6	15.2	18.4	17.4	35.5	24.9	16.2	21.1
	1001 - 1500 ft (305 - 457 m)		18.0	20.5	27.5	11.7	12.9	41.4	23.3	29.2	26.7
	1501 - 2000 ft (458 - 609 m)		36.0	41.3	10.5	17.3	30.8	8.7	20.2	27.6	25.5
	2001 - 2500 ft (610 - 762 m)		2.7	0.0	0.0	39.7	2.9	0.0	0.0	17.8	21.1

*Measured from first cone back toward first sign.

TABLE 2

DATA FOR LEFT-LANE CLOSURES
PHASE 1

			DATA SET NUMBERS								
			L 1.1	L 1.2	L 1.3	L 1.4	L 1.5	L 1.6	L 1.7	L 1.8	L 1.9
Sign Color			YELLOW	YELLOW	YELLOW	YELLOW	YELLOW	YELLOW	YELLOW	YELLOW	YELLOW
Volumes	Cars		437	539	513	724	532	480	429	218	699
	Trucks		59	73	87	54	54	63	93	49	64
	Total		496	612	600	778	586	543	522	267	763
Sight Distances to	First Sign	(miles)	0.60	0.40	0.25		0.60	0.40	0.70	0.15	0.25
		(kilometers)	0.97	0.64	0.40		0.97	0.64	1.13	0.24	0.40
	Flashing Arrow	(miles)	1.10	0.50	0.35		1.00	0.40	0.55		0.55
		(kilometers)	1.77	0.80	0.56		1.61	0.64	0.89		0.89
Design Elements --	Grade		+	+ to -	-	-	+	+ to -	Level	-	-
	Curve		Tan	Tan to Lt	Tan to Lt	Lt	Lt to Rt	Tan to Lt	Lt to Rt	Tan	Lt
Mean Speeds At First Sign	Cars	(mph)	67.5	65.5	67.1	66.5	70.0	65.6	67.8	64.3	68.4
		(m/s)	30.2	29.3	30.0	29.7	31.3	29.3	30.3	28.7	30.6
	Trucks	(mph)	59.6	56.1	56.6	54.7	64.9	65.5	62.6	56.9	56.7
		(m/s)	26.6	25.1	25.3	24.5	29.0	29.3	28.0	25.4	25.3
Mean Speeds At First Cone	Cars	(mph)	54.5	53.9	60.0	59.6	48.1	54.5	58.5	57.4	50.2
		(m/s)	24.4	24.1	26.8	26.6	21.5	24.4	26.1	25.7	22.5
	Trucks	(mph)	45.7	53.5	56.7	53.3	47.6	54.0	55.4	51.8	47.1
		(m/s)	20.4	23.9	25.3	23.8	21.3	24.1	24.8	23.2	21.0
Mean Speeds Decrease	Cars	(mph)	13.0	11.6	7.1	6.9	21.9	11.1	9.3	6.9	18.1
		(m/s)	5.8	5.2	3.2	3.1	9.8	4.9	4.2	3.0	8.1
	Trucks	(mph)	13.9	2.6	+0.1	1.4	17.3	11.5	7.2	5.1	9.6
		(m/s)	6.2	1.2	0.0	0.7	7.7	5.2	3.2	2.2	4.3
Conflicts	Abnormal Braking		15	5	11	12	13	11	4	6	14
	Forced Merges		3	2	3	6	2	3	0	8	7
	Complete Stops		0	0	0	0	0	0	0	0	0
	Total		18	7	14	18	15	14	4	14	21
Turn Signals			16	35	25	45	23	34	28	14	24
Percent Merges with Turn Signals			14.3	25.0	13.4	18.4	11.4	20.5	22.1	15.9	12.5
Distance between First Sign and First Cone		(ft)	2500	3015	2238	2238	2571	2788	2181	3200	2260
		(meters)	762	919	682	682	784	850	665	975	689
Percent Merges Occurring within*	0 - 500 ft (0 - 152 m)		6.4	11.0	20.9	12.7	15.9	30.1	7.1	51.1	17.7
	501 - 1000 ft (153 - 304 m)		11.0	19.0	13.9	18.9	24.6	16.1	13.4	19.3	16.2
	1001 - 1500 ft (305 - 457 m)		21.1	21.0	27.8	25.8	18.5	13.3	12.6	14.8	24.0
	1501 - 2000 ft (458 - 609 m)		19.3	22.0	29.4	33.2	15.4	10.5	44.9	12.5	27.6
	2001 - 2500 ft (610 - 762 m)		42.2	27.0	8.0	9.4	25.6	30.1	22.1	2.3	14.6

*Measured from first cone back toward first sign.

TABLE 3

DATA FOR RIGHT-LANE CLOSURES
PHASE 2

			DATA SET NUMBERS																			
			R 2.1	R 2.1	R 2.2	R 2.2	R 2.3	R 2.3	R 2.4	R 2.4	R 2.5	R 2.5	R 2.6	R 2.6	R 2.7	R 2.7	R 2.8	R 2.8	R 2.9	R 2.9	R 2.10	R 2.10
Sign Color			YELLOW	ORANGE	YELLOW	ORANGE	YELLOW	ORANGE	YELLOW	ORANGE	YELLOW	ORANGE	YELLOW	ORANGE	YELLOW	ORANGE	YELLOW	ORANGE	YELLOW	ORANGE	YELLOW	ORANGE
Volumes	Cars		304	359	345	322	165	152	325	385	299	360	214	184	148	198	291	291	327	351	278	286
	Trucks		77	62	82	65	40	36	56	66	61	98	86	68	72	54	80	56	88	93	44	40
	Total		381	421	427	387	205	188	381	451	360	458	300	252	220	252	371	347	415	444	322	326
Sight Distances to	First Sign	(miles)	0.30	0.30	0.40	0.40	0.30	0.30	1.00	1.00	0.55	0.55	0.30	0.30	0.60	0.60	0.30	0.30	0.40	0.40	0.85	0.85
		(kilometers)	0.48	0.48	0.64	0.64	0.48	0.48	1.61	1.61	0.89	0.89	0.48	0.48	0.97	0.97	0.48	0.48	0.64	0.64	1.37	1.37
	First Cone	(miles)							0.50	0.50	0.20	0.20	0.20	0.20	0.20	0.20	0.80	0.80	0.28	0.28	0.35	0.35
		(kilometers)							0.80	0.80	0.32	0.32	0.32	0.32	0.32	0.32	1.29	1.29	0.45	0.45	0.56	0.56
Design Elements --	Grade		Level	Level	Level	Level	Level	Level	-	-	-	-	-	+ to +	+ to -	+ to -	Level	Level	+ to -	+ to -	+ to -	+ to -
	Curve		Lt	Lt	Lt	Lt	Lt	Lt	Lt	Lt	Lt to Rt	Lt to Rt	Rt	Rt	Tan	Tan	Tan	Tan	Rt to Tan	Rt to Tan	Tan to Rt	Tan to Rt
Mean Speeds At First Sign	Cars	(mph)	68.2	67.3	68.5	70.0	65.4	66.2	69.3	70.0	70.4	67.3	70.0	70.5	70.2	70.4	69.9	69.5	70.0	69.7	65.5	66.8
		(m/s)	30.5	30.1	30.6	31.3	29.2	29.6	31.0	31.3	31.5	30.1	31.3	31.5	31.4	31.5	31.3	31.1	31.3	31.2	29.3	29.9
	Trucks	(mph)	63.8	63.3	64.0	62.2	60.3	57.8	64.0	63.3	66.3	61.5	62.5	61.8	61.9	60.8	62.5	61.5	59.8	60.2	48.8	53.4
		(m/s)	28.5	28.3	28.6	27.8	27.0	25.8	28.6	28.3	29.7	27.5	27.9	27.6	27.7	27.2	27.9	27.5	26.7	26.9	21.8	23.9
Mean Speeds At First Cone	Cars	(mph)	52.5	50.2	49.7	50.2	49.1	52.3	50.9	50.2	52.6	51.0	51.7	52.5	57.2	57.1	52.8	52.2	50.9	50.9	48.5	53.5
		(m/s)	23.5	22.4	22.2	22.5	21.9	23.4	22.8	22.4	23.5	22.8	23.1	23.5	25.6	25.5	23.6	23.4	22.7	22.8	21.7	23.9
	Trucks	(mph)	51.9	50.2	48.9	51.0	44.3	49.0	52.9	51.5	50.9	45.9	51.6	51.8	50.4	51.8	51.5	51.3	49.8	50.1	47.3	47.5
		(m/s)	23.2	22.4	21.9	22.8	19.8	21.9	23.7	23.0	22.7	20.5	23.1	23.2	22.6	23.2	23.0	22.9	22.3	22.4	21.1	21.2
Decrease	Cars	(mph)	15.7	17.1	18.8	19.8	16.3	13.9	18.4	19.8	17.8	16.3	18.3	18.0	13.0	13.3	17.1	17.3	19.1	18.8	17.0	13.3
		(m/s)	7.0	7.7	8.4	8.8	7.3	6.2	8.2	8.9	8.0	7.3	8.2	8.0	5.8	6.0	7.7	7.7	8.6	8.4	7.6	6.0
	Trucks	(mph)	11.9	13.1	15.1	11.2	16.0	8.8	11.1	11.8	15.4	15.6	10.9	10.0	11.5	9.0	11.0	10.2	10.0	10.1	1.5	5.9
		(m/s)	5.3	5.9	6.7	5.0	7.2	3.9	4.9	5.3	6.9	7.0	4.9	4.5	5.1	4.0	4.9	4.6	4.4	4.5	0.7	2.7
Conflicts	Abnormal Braking		2	3	6	3	5	0	3	3	10	8	2	2	2	0	0	0	11	25	18	4
	Forced Merges		0	2	2	2	2	0	4	3	3	0	0	0	0	0	1	0	0	1	0	0
	Complete Stops		0	0	0	0	0	0	0	0	3	0	2	0	0	0	0	0	2	1	0	0
	Total		2	5	8	5	7	0	7	6	16	8	4	2	2	0	1	0	13	27	18	4
Turn Signals			22	32	38	40	20	24	57	58	22	40	48	32	46	34	42	25	45	41	24	16
Percent Merges with Turn Signals			7.0	10.2	10.6	12.5	10.4	14.1	18.6	16.7	7.4	12.0	22.2	16.5	23.7	18.1	16.6	10.5	14.0	13.2	9.3	7.5
Distance between First Sign and First Cone		(ft)	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
		(meters)	762	762	762	762	762	762	762	762	762	762	762	762	762	762	762	762	762	762	762	762
Percent Merges Occurring within*	0 - 500 ft (0 - 152 m)		2.2	2.6	3.6	2.5	16.6	28.2	6.5	7.5	20.0	9.0	23.2	14.4	11.3	17.0	1.6	0.8	2.5	2.9	12.4	1.9
	501 - 1000 ft (153 - 304 m)		8.9	6.1	19.3	15.3	30.1	18.8	18.0	13.5	12.0	13.2	20.4	22.7	18.6	24.5	6.7	5.9	13.4	15.5	30.2	17.8
	1001 - 1500 ft (305 - 457 m)		16.5	15.0	22.9	22.1	19.2	21.2	17.0	12.6	7.4	7.8	13.0	10.3	13.4	17.0	11.4	8.4	18.7	16.4	8.5	17.8
	1501 - 2000 ft (458 - 609 m)		20.3	21.1	21.2	20.3	11.4	11.8	14.1	13.2	12.4	16.8	14.8	16.5	14.4	12.8	22.9	21.4	23.1	18.7	7.8	14.0
	2001 - 2500 ft (610 - 762 m)		52.2	55.3	33.0	35.8	22.8	20.0	44.4	53.2	48.2	53.3	28.7	35.1	42.3	28.7	57.3	63.5	42.4	46.5	41.1	48.6

*Measured from first cone back toward first sign.

TABLE 4

DATA FOR LEFT-LANE CLOSURES PHASE 2

		DATA SET NUMBERS													
		L 2.1	L 2.1	L 2.2	L 2.2	L 2.3	L 2.3	L 2.4	L 2.4	L 2.5	L 2.5	L 2.6	L 2.6	L 2.7	L 2.7
Sign Color		YELLOW	ORANGE	YELLOW	ORANGE	YELLOW	ORANGE	YELLOW	ORANGE	YELLOW	ORANGE	YELLOW	ORANGE	YELLOW	ORANGE
Volumes	Cars	432	462	326	334	664	561	456	576	538	532	340	375	556	600
	Trucks	46	40	46	53	93	76	48	58	54	58	76	57	54	70
	Total	478	502	372	387	757	637	504	634	592	590	416	432	610	670
Sight Distances to	First Sign (miles)	0.85	0.85	0.85	0.85	0.80	0.80	0.30	0.30	0.30	0.30	0.40	0.40	0.40	0.40
	(kilometers)	1.37	1.37	1.37	1.37	1.28	1.28	0.48	0.48	0.48	0.48	0.64	0.64	0.64	0.64
	Flashing Arrow (miles)	0.35	0.35	0.35	0.35			0.40	0.40	0.30	0.30	0.90	0.90	0.40	0.40
	or First Cone (kilometers)	0.56	0.56	0.56	0.56			0.64	0.64	0.48	0.48	1.45	1.45	0.64	0.64
Design Elements --	Grade	+ to -	+ to -	+ to -	+ to -	+	+	-	-	- to +	- to +	Level	Level	Level	Level
	Curve	Rt	Rt	Tan to Rt	Tan to Rt	Tan	Tan	Lt	Lt	Tan to Rt	Tan to Rt	Tan	Tan	Rt to Lt	Rt to Lt
Mean Speeds At First Sign	Cars (mph)	67.4	68.4	68.6	69.5	69.7	69.1		65.0	71.3	69.9	66.8	68.0	66.6	67.2
	(m/s)	30.1	30.6	30.7	31.1	31.2	30.9		29.1	31.9	31.2	29.9	30.4	29.8	30.0
	Trucks (mph)	56.2	58.2	57.2	58.4	64.1	64.3		54.7	65.1	64.0	62.0	63.1	60.9	60.1
	(m/s)	25.1	26.0	25.6	26.1	28.7	28.9		24.4	29.1	28.6	27.7	28.2	27.2	26.9
Mean Speeds At First Cone	Cars (mph)	53.8	52.3	54.5	54.1	48.0	54.1		55.1	47.4	50.9	51.1	49.6	53.2	49.3
	(m/s)	24.0	23.4	24.4	24.2	21.5	24.2		24.6	21.2	22.8	22.9	22.2	23.8	22.1
	Trucks (mph)	45.3	50.6	50.7	52.5	50.3	48.3		51.5	49.7	50.8	45.8	58.1	44.3	49.6
	(m/s)	20.2	22.6	22.7	24.5	22.5	21.6		23.0	22.2	22.7	20.5	26.0	19.8	22.2
Mean Speeds Decrease	Cars (mph)	13.6	16.1	14.1	15.4	21.7	15.0		9.9	23.9	19.0	15.7	18.4	13.4	17.9
	(m/s)	6.1	7.2	6.3	7.9	9.7	6.7		4.5	10.7	8.5	7.0	8.2	6.0	7.9
	Trucks (mph)	10.9	7.6	6.5	5.9	13.8	16.0		3.2	15.4	13.2	16.2	5.0	16.6	10.5
	(m/s)	4.9	3.4	2.9	1.6	6.2	7.2		1.4	6.9	5.9	7.2	2.2	7.4	4.7
Conflicts	Abnormal Braking	14	8	17	15	6	1	0	0	14	4	1	2		
	Forced Merges	0	2	1	4	5	0	0	0	4	0	2	0		
	Complete Stops	0	0	2	0	0	0	0	0	0	0	0	0		
	Total	14	10	20	19	11	1	0	0	18	4	3	2		
Turn Signals		22	24	10	12	26	11	14	29	44	10	10	10	12	34
Percent Merges with Turn Signals		18.0	20.0	11.5	14.5	14.1	7.8	7.9	14.9	19.3	4.8	9.6	11.0	5.8	16.4
Distance between First Sign and First Cone	(ft)	2500	2500	2500	2500	5000	5000	2700	2700	2536	2536	3170	3170	2283	2383
	(meters)	762	762	762	762	1524	1524	823	823	773	773	966	966	726	726
Percent Merges Occurring within*	0 - 500 ft (0 - 152 m)	10.0	3.3	5.8	8.4	37.4	18.3	28.4	12.1	9.7	13.3	6.8	11.8	14.5	12.5
	501 - 1000 ft (153 - 304 m)	11.7	16.7	10.3	7.2	5.6	8.5	12.2	6.4	18.4	20.0	17.6	22.1	13.6	10.6
	1001 - 1500 ft (305 - 457 m)	10.0	3.3	17.2	12.1	5.6	11.3	13.5	13.4	23.7	18.1	37.8	19.1	26.2	23.1
	1501 - 2000 ft (458 - 609 m)	25.0	18.3	23.0	19.3	20.6	29.6	14.9	24.8	20.2	23.8	17.6	19.1	17.5	26.9
	2001 - 2500 ft (610 - 762 m)	43.3	56.7	43.7	53.0	30.8	32.4	31.1	43.3	28.1	24.8	20.3	27.9	28.2	26.9

*Measured from first cone back toward first sign.

TABLE 5

AUTO SPEEDS

PHASE	COLOR	LANE CLOSED	MEAN SPEED AT FIRST SIGN (mph)	(m/s)	MEAN SPEED AT FIRST CONE (mph)	(m/s)	MEAN DECREASE (mph)	(m/s)
1	Yellow	Right	66.2	29.6	54.5	24.4	11.7	5.2
2	Yellow	Right	68.7	30.7	51.6	23.1	17.1	7.6
2	Orange	Right	68.7	30.7	52.0	23.2	16.7	7.5
1	Yellow	Left	67.0	30.0	55.2	24.7	11.8	5.3
2	Yellow	Left	68.4	30.6	51.3	22.9	17.1	7.7
2	Orange	Left	68.2	30.5	52.2	23.3	16.0	7.2

.005 .005 .05 .05

Significance and level of significance are indicated by brackets.
Left and right lane closures were not tested together.

TABLE 6

TRUCK SPEEDS

PHASE	COLOR	LANE CLOSED	MEAN SPEED AT FIRST SIGN (mph)	(m/s)	MEAN SPEED AT FIRST CONE (mph)	(m/s)	MEAN DECREASE (mph)	(m/s)
1	Yellow	Right	59.0	26.4	50.4	22.5	8.6	3.9
2	Yellow	Right	61.4	27.4	50.0	22.3	11.4	5.1
2	Orange	Right	60.6	27.1	50.0	22.3	10.6	4.8
1	Yellow	Left	58.7	26.2	51.6	23.1	7.1	3.1
2	Yellow	Left	60.9	27.2	47.7	21.3	13.2	5.9
2	Orange	Left	60.4	27.0	50.2	22.4	10.2	4.6

.10 .10 .025

Significance and level of significance are indicated by brackets.
Left and right lane closures were not tested together.

TABLE 7

MEAN 85th PERCENTILE SPEEDS

PHASE	COLOR	LANE CLOSED	AUTOS				TRUCKS			
			SPEED AT FIRST SIGN		SPEED AT FIRST CONE		SPEED AT FIRST SIGN		SPEED AT FIRST CONE	
			(mph)	(m/s)	(mph)	(m/s)	(mph)	(m/s)	(mph)	(m/s)
1	Yellow	Right	70.7	31.6	60.5	27.0	64.6	28.9	55.3	24.7
2	Yellow	Right	73.3	32.8	58.8	26.3	65.5	29.3	55.6	24.9
2	Orange	Right	74.4	33.3	58.8	26.3	64.4	28.8	55.7	24.9
1	Yellow	Left	71.6	32.0	61.0	27.3	63.3	28.3	57.1	25.5
2	Yellow	Left	73.8	33.0	58.4	26.1	65.3	29.2	53.0	23.7
2	Orange	Left	73.4	32.8	58.1	26.0	64.8	30.0	56.1	25.1

TABLE 8

MEAN CONFLICTS PER 100 VEHICLES

PHASE	COLOR	LANE CLOSED	MEAN CONFLICTS PER 100 VEHICLES	
1	Yellow	Right	5.64	.01
2	Yellow	Right	2.33	.001
2	Orange	Right	1.37	
1	Yellow	Left	2.59	.20
2	Yellow	Left	2.25	
2	Orange	Left	1.37	

Significance and level of significance are indicated by brackets.
Left and right lane closures were not tested together.

TABLE 9

PERCENT OF MERGES WITHIN 500 FEET (152 METERS) OF THE FIRST TRAFFIC CONE

PHASE	COLOR	LANE CLOSED	PERCENT MERGES WITHIN 500 FT (152 M) OF FIRST CONE
1	Yellow	Right	21.3
2	Yellow	Right	10.0
2	Orange	Right	8.7
1	Yellow	Left	19.2
2	Yellow	Left	16.1
2	Orange	Left	11.4

.05 .05 .20

Significance and level of significance are indicated by brackets.
Left and right lane closures were not tested together.

TABLE 10

TURN SIGNAL INDICATIONS

PHASE	COLOR	LANE CLOSED	MEAN PERCENT OF MERGES WITH TURN SIGNAL
1	Yellow	Right	23.2
2	Yellow	Right	14.0
2	Orange	Right	13.1
1	Yellow	Right	17.1
2	Yellow	Left	12.3
2	Orange	Left	12.7

.0001 .00001 .10 .10

Significance and level of significance are indicated by brackets.
Left and right lane closures were not tested together.

TABLE 11

RESPONSES TO DRIVER INTERVIEW

1. Did you notice two different colored warning signs prior to the lane closure?

Yes	38
No	24

2. If yes, what colors did you notice?

Yellow	34
Orange	25
Red	13
Other	4

3. If only one color noticed, what was it?

Yellow	6
Orange	1
Red	1
Red-Orange	1
Other	1
Uncertain	14

4. If two colors were noticed, which one seemed more effective? (Only asked people who replied "yes" to question one).

Yellow	9
Orange	23
Red	4
Uncertain	2

5. Do you think you are adequately made aware that a lane is closed ahead at sites like this?

Yes	56
No	6

6. What is your biggest complaint about these sites?

Nothing	52
Other	10

7. Do you think the warning signs are usually spaced properly so you can rely upon what they say?

Yes	58
No	3
Uncertain	1

8. Do you actually merge into the open lane when you see the first warning sign, whenever you can, or when you actually see the lane blocked off?

First Sign	31
Whenever	19
Actual Lane Blocked	12

LIST OF FIGURES

Figure 1. Research Personnel Positioning New Signs over Contractors' Signs.

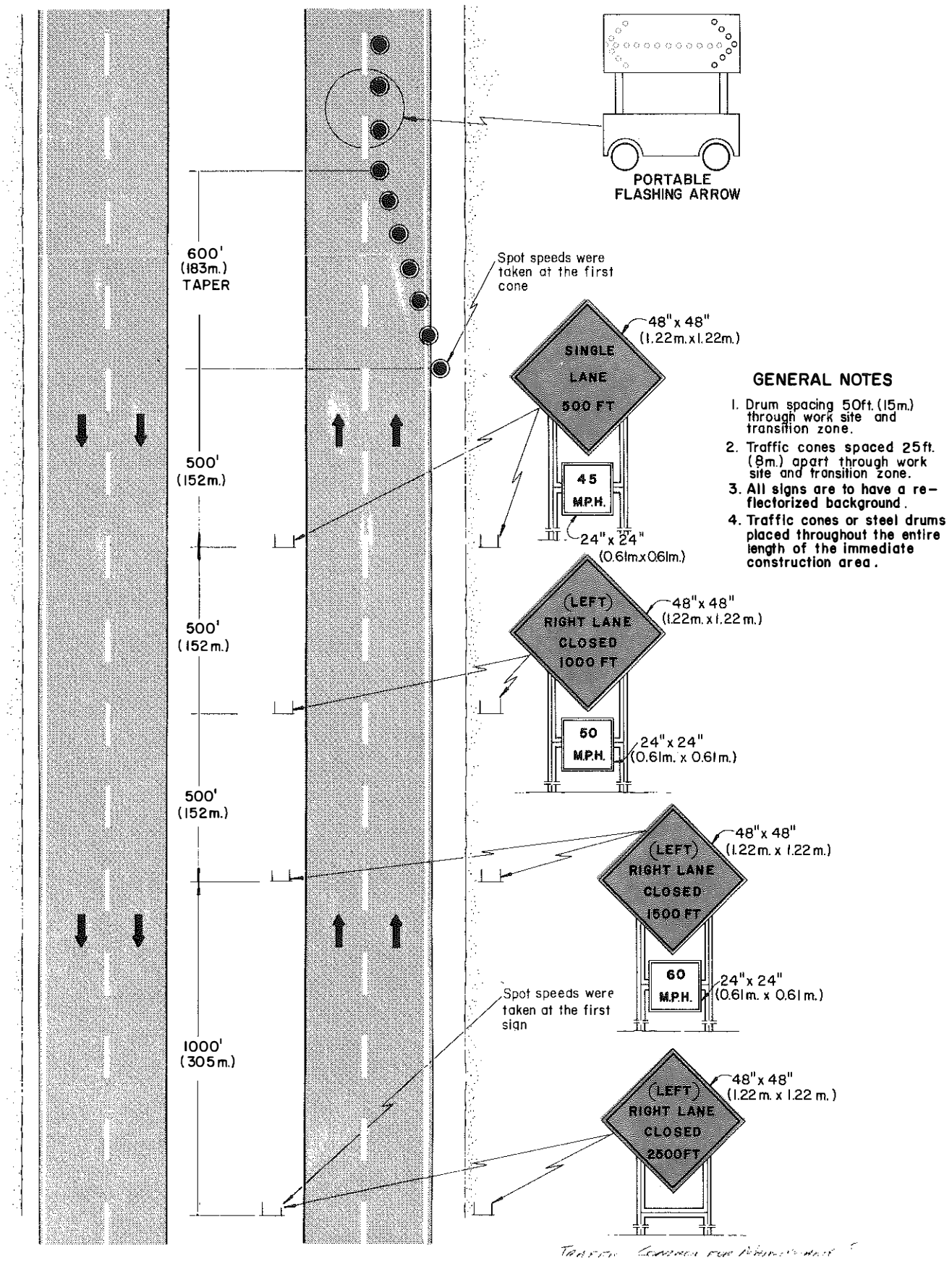

Figure 2. Lane Closure Detail Showing Sign Scheme Used.

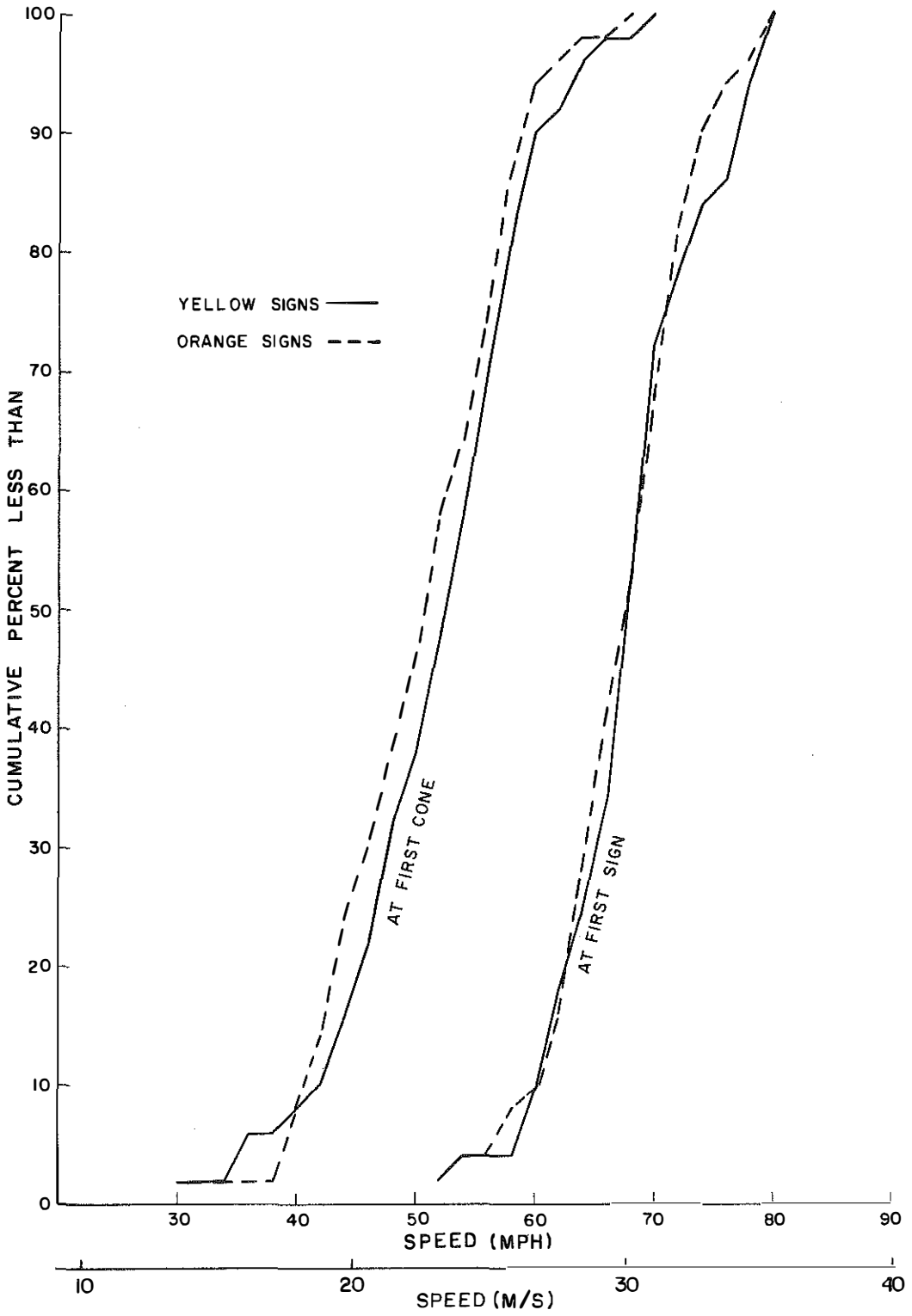

Figure 3. Cumulative Distributions of Speeds at a Site Where Both Sign Colors Were Used.

Figure 4. Contractor's Sign (top) as Contrasted with Test Sign.

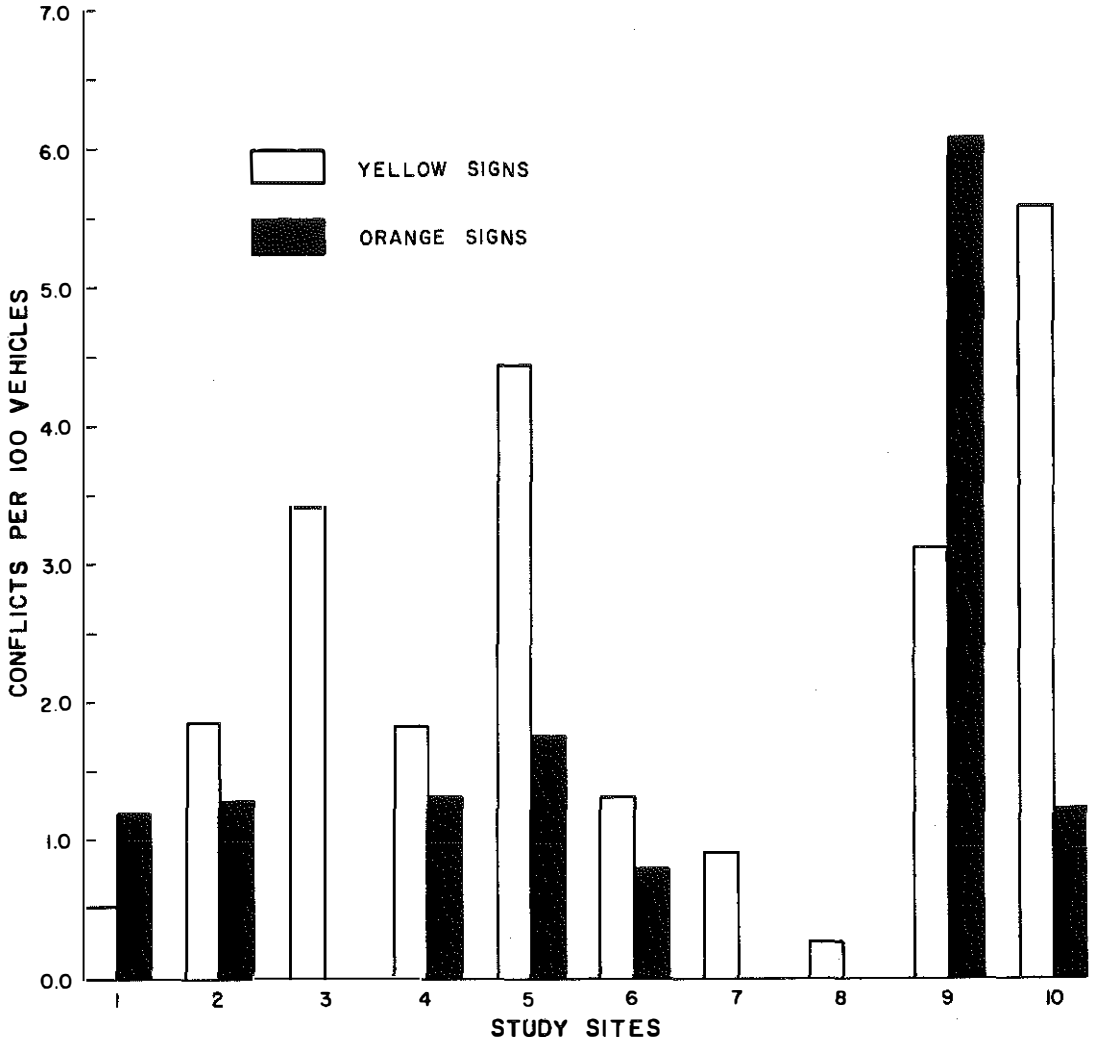

Figure 5. Conflicts per 100 Vehicles at Each Study Site (Right Lane Closures, Phase 2).

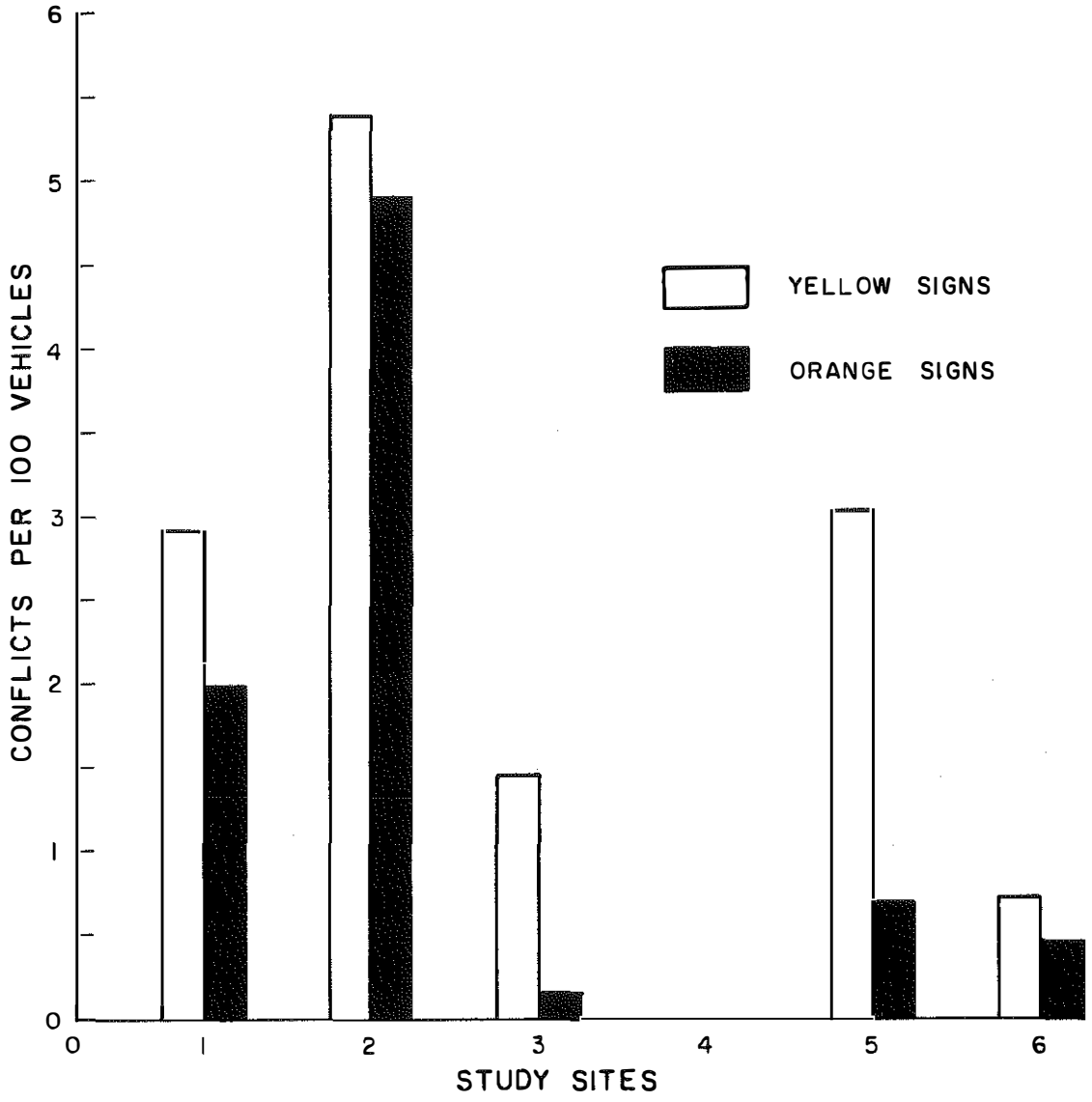

Figure 6. Conflicts per 100 Vehicles at Each Study Site (Left Lane Closures, Phase 2).

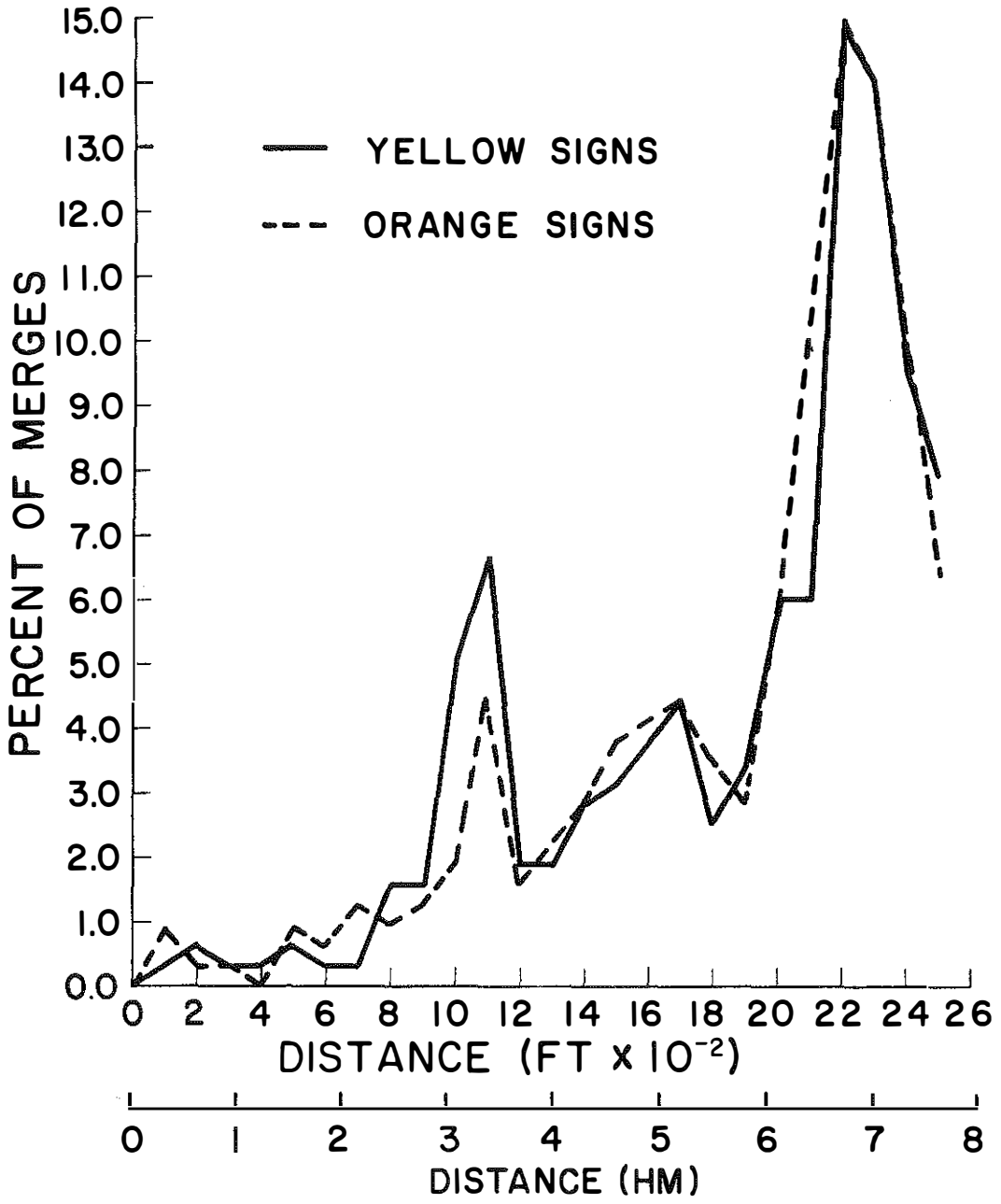

Figure 7. Merge Distributions at Site R 2.1.

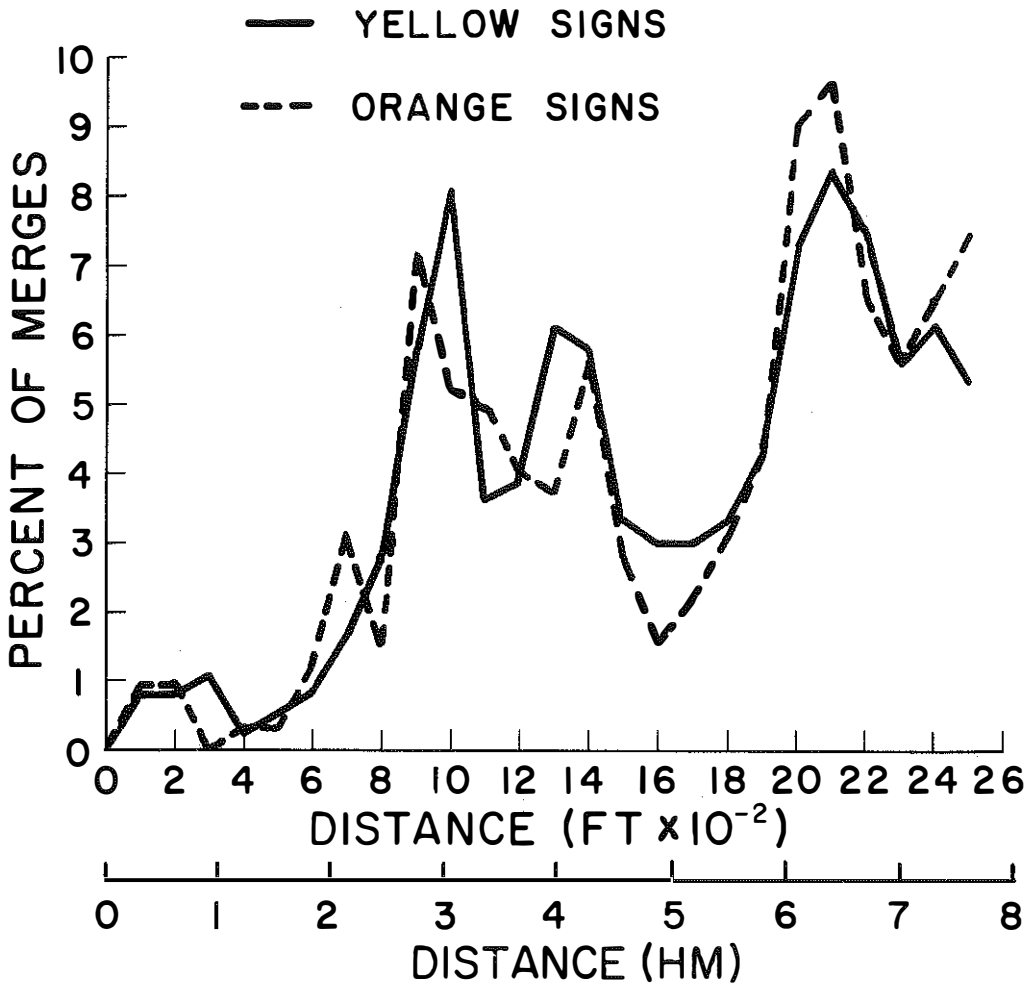

Figure 8. Merge Distributions at Site R 2.2.

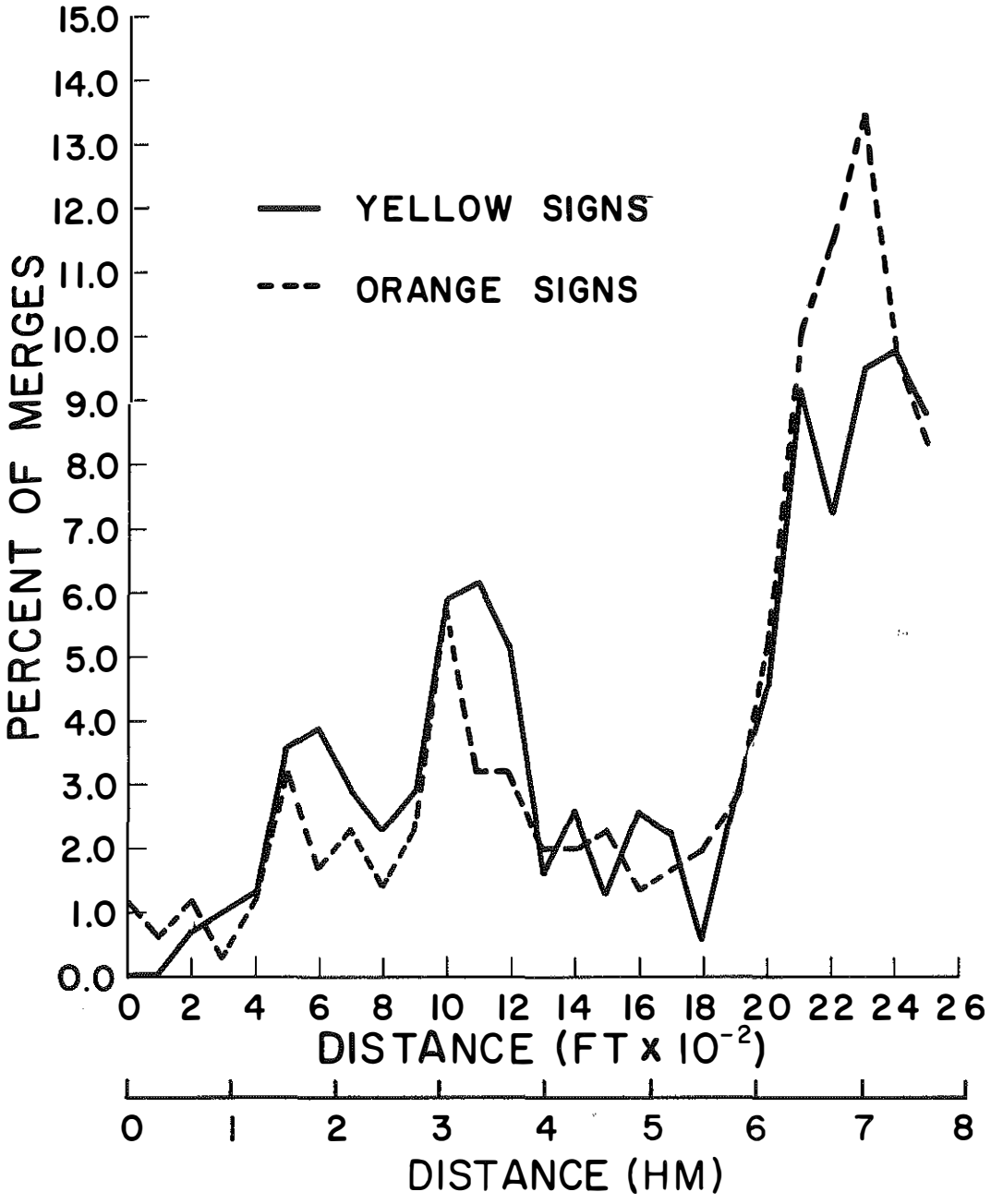

Figure 9. Merge Distributions at Site R 2.4.

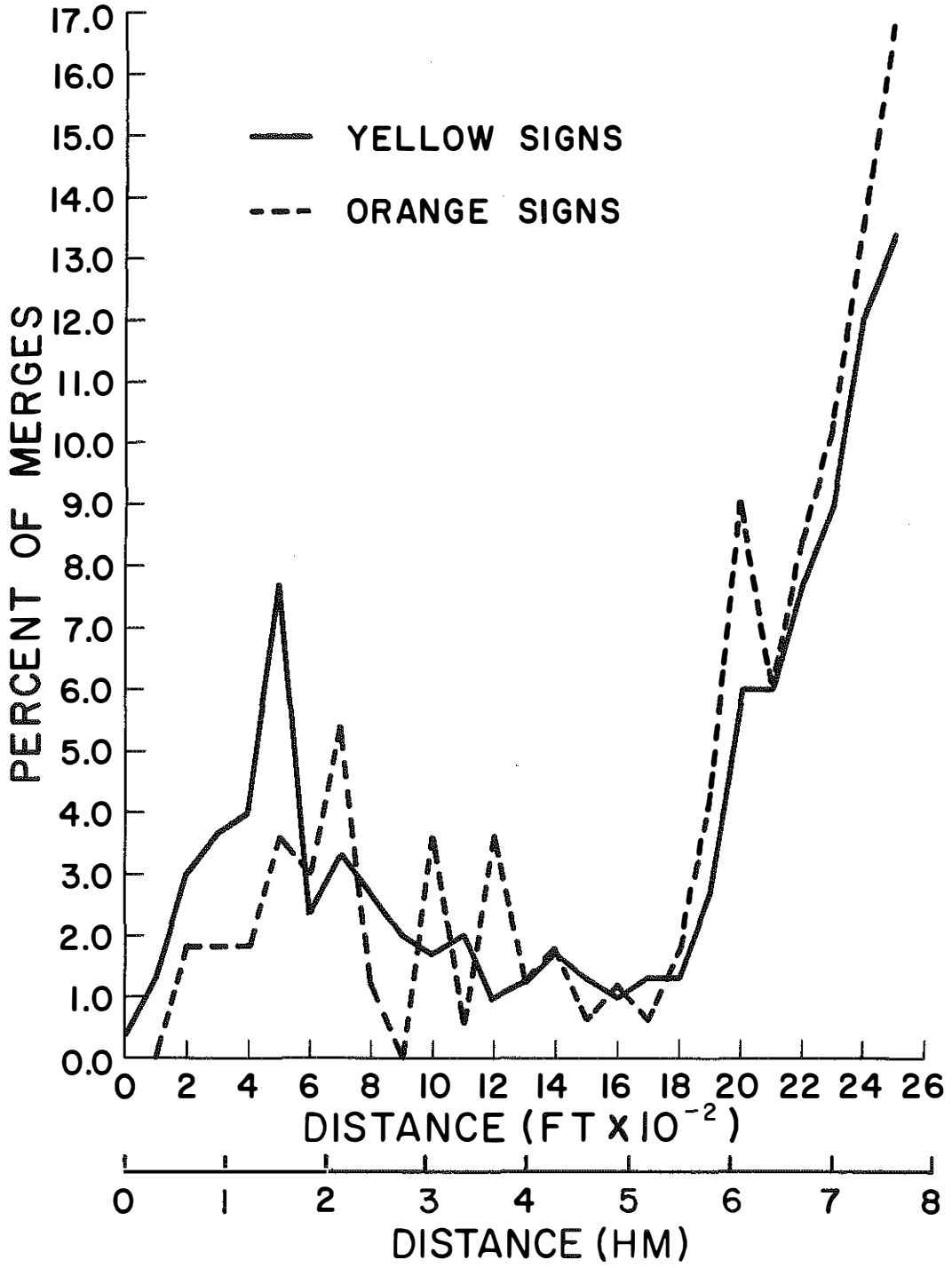

Figure 10. Merge Distributions at Site R 2.5.

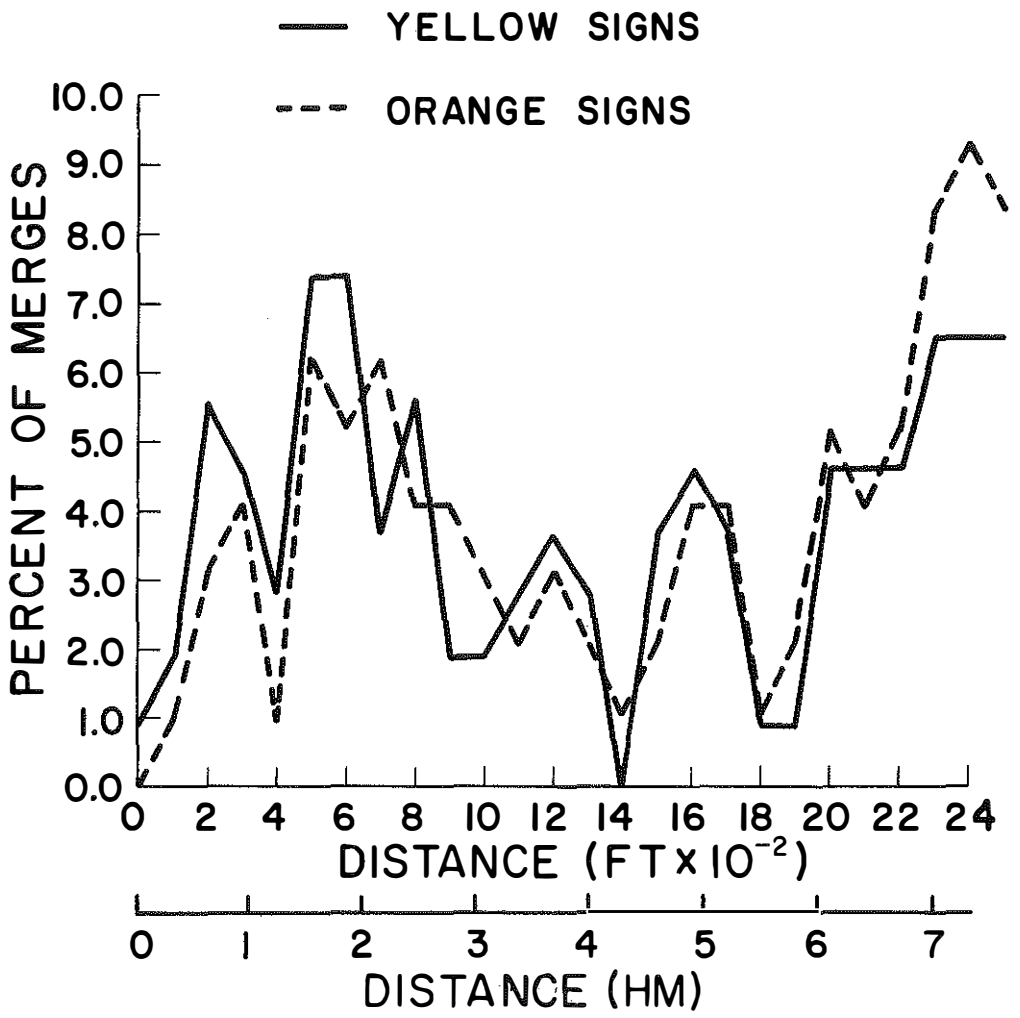

Figure 11. Merge Distributions at Site R 2.6.

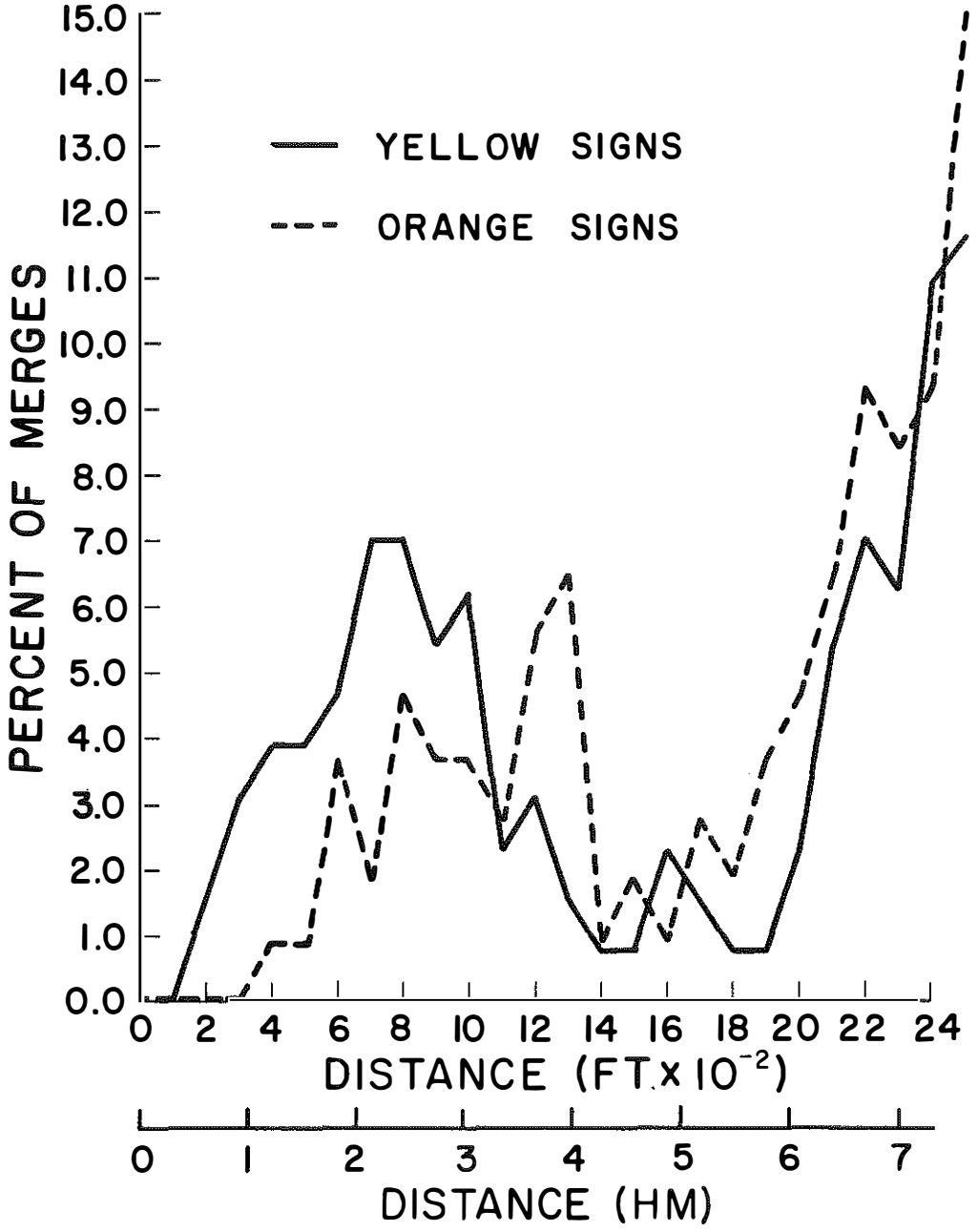

Figure 12. Merge Distributions at Site R 2.10.

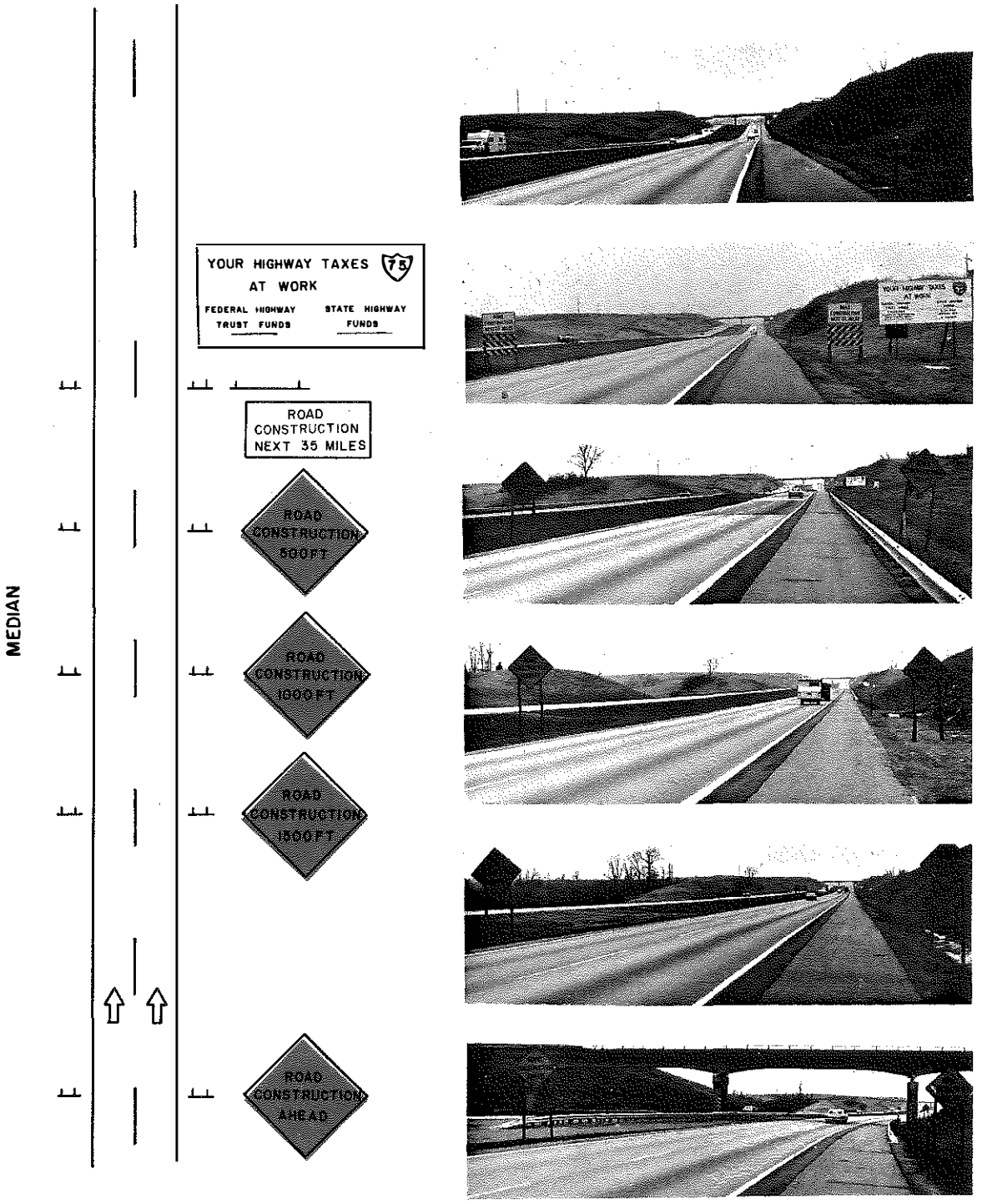

Figure 13. Sign Scheme Preceeding an Extensive Maintenance Project. Top Photo Shows No Maintenance or Construction in Sight.

Figure 14. Errors which Cause Confusion and Disrespect for Warning Signs.