COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT, KENTUCKY 40601

CHARLES PRYOR, JR.
COMMISSIONER OF HIGHWAYS

May 3, 1972

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H.2.61

MEMORANDUM TO: J. R. Harbison
State Highway Engineer
Chairman, Research Committee

SUBJECT: Research Report 327, "Traffic Controls for Maintenance on High Speed Highways"; KYHPR-70-61; HPR-1(7), Part II.

As the pressure and momentum of traffic on multilane highways increase, and as the needs for repairs and revisions mount, adequate signing and barricading for lane closures presents an ever-increasing challenge. Constricting a stream of rushing water would be much simpler. Obedience of drivers to sign messages seems essential if greater assurances of safety are to be achieved. This seems to be the most significant finding from the subject study. The report, included herewith, reveals, in inferable ways, an astonishing degree of insensitivity toward signing. More amazing, perhaps, is the high percentage of drivers interviewed who admitted to a degree of disobedience. Unfortunately, in this study the percentage of drivers making such admissions and who were involved in desperation maneuvers was not determined.

A similar but more comprehensive study has been completed recently by the Virginia Department of Highways ("Highway Signing for Safety," F. D. Shepard, June 1971). There, too, a degree of insensitivity seems evident.

Although the necessity of maintaining signs in good condition and position is intuitively evident, perfection of safety controls for both motorist and worker is not likely to arise through signing innovations alone.

Respectfully submitted,

Jas. H. Havens
Director of Research

JHH/dw
Attachment
cc's: Research Committee

TECHNICAL REPORT STANDARD TITLE PAGE

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Study Title: Analysis of Traffic Control on High Speed Facilities during Maintenance

16. 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. The results of the study tend to support the adoption of orange as the standard color for signing construction and maintenance sites. However, the 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.

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Research Report
327

TRAFFIC CONTROLS FOR MAINTENANCE ON HIGH SPEED HIGHWAYS

FINAL REPORT
KYHPR-70-61; HPR-1(7), Part II

by

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Division of Research
DEPARTMENT OF HIGHWAYS
Commonwealth of Kentucky

in cooperation with the
U.S. Department of Transportaiton
FEDERAL HIGHWAY ADMINISTRATION

May 1972

INTRODUCTION

Maintenance work which requires barricading one or more lanes of a high-speed roadway creates a potential hazard to the unwary traveller 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. This report is concerned with traffic control signs and driver obedience. Here, obedience is used as a measure of effective signing.

Standards for temporary signing have been rather difficult to develop and implement *(1)*. 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 travellers have proven to be helpful in managing these situations.

The 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.

During the study period, orange signs were considered experimental; and the study thus became a test of orange signs. Yellow and orange signs were easily compared on an individual site basis when data were collected on each color at the same site. Each day, though, studies were made at a different site. 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.

When analyzing the data, it became apparent that many variables interacted to produce a result. No attempt was made to quantify variables such as gap length, traffic flow characteristics (platooning effect), driver risk-taking, or driver behavior in general, although some inferences might have been drawn about them. Driver interviews were conducted and are reported.

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. This work necessitated numerous lane closures involving virtually all types of rural, geometric design features. Research personnel were able to observe and collect data on various situations at the lane closures. The cooperation of the contractors was excellent throughout the study.

In Phase 1, observations were made at sites signed by contractors. In Phase 2, the contractor's signs were replaced with new, yellow signs, and then with new orange signs (simulating new standard, then pending) *(2)*. Phase 2 also included observation of the new signs at sites where other research activities required lane closures. Phase 1 thus included actual field practices with regard to sign placement, sign condition, etc. Phase 2 provided only direct comparison between yellow and orange signs. The new, yellow signs were merely hung over the contractors' signs (Figure 1); traffic was observed for one hour; then the new, orange signs were superposed; and observations continued for another hour. At those sites manned solely by research staff, care was taken to position the signs according to the signing scheme shown in Figure 2.

Data collection included spot speeds, traffic conflicts, merging maneuvers and turn-signal indications. A discussion of each of these follows.

SPOT SPEEDS

Radar spot-speeds were taken at the first sign (2500-foot 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. A typical radar location from which speeds at the first sign

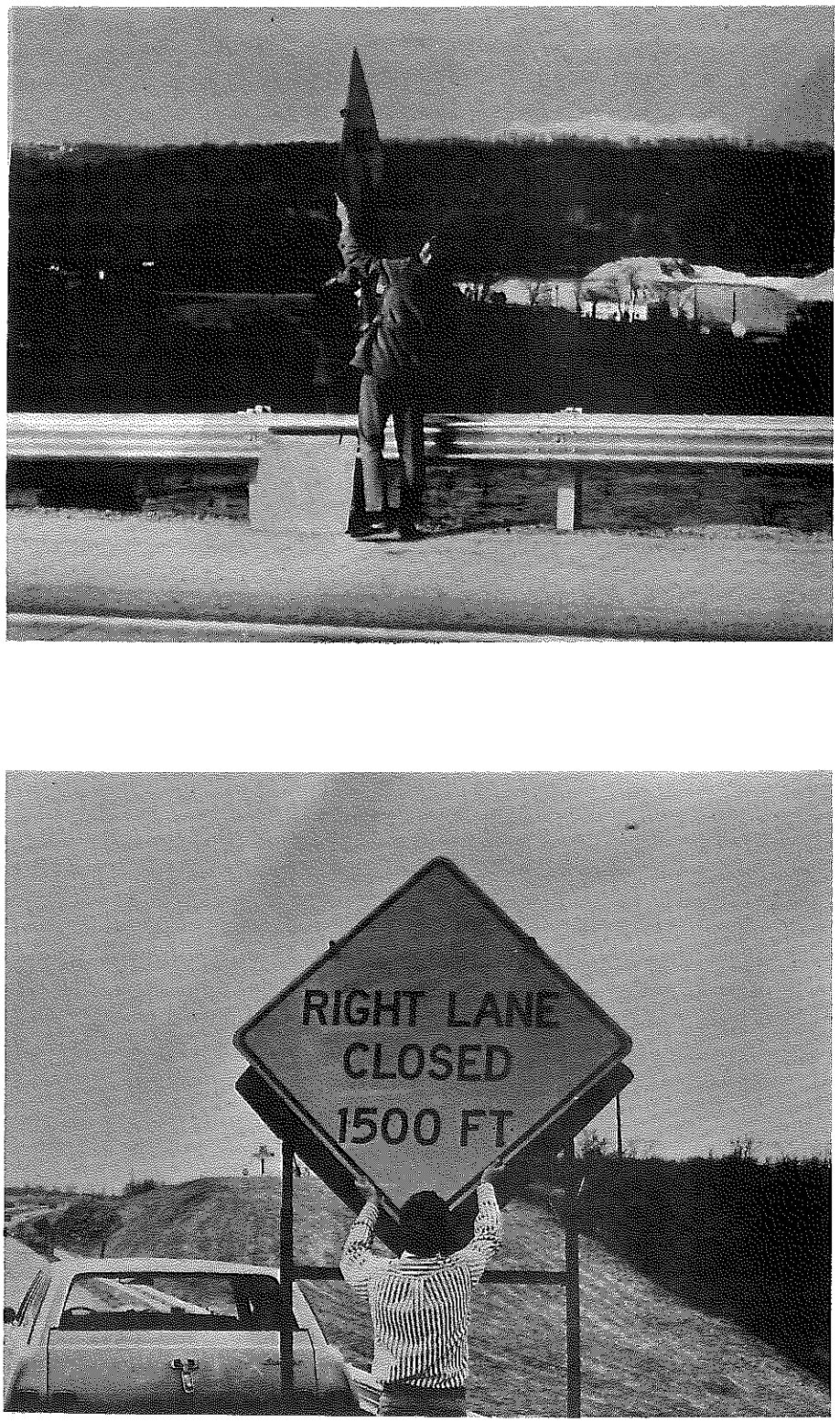


Figure 1. Research Personnel Positioning New Signs over Contractors' Signs.

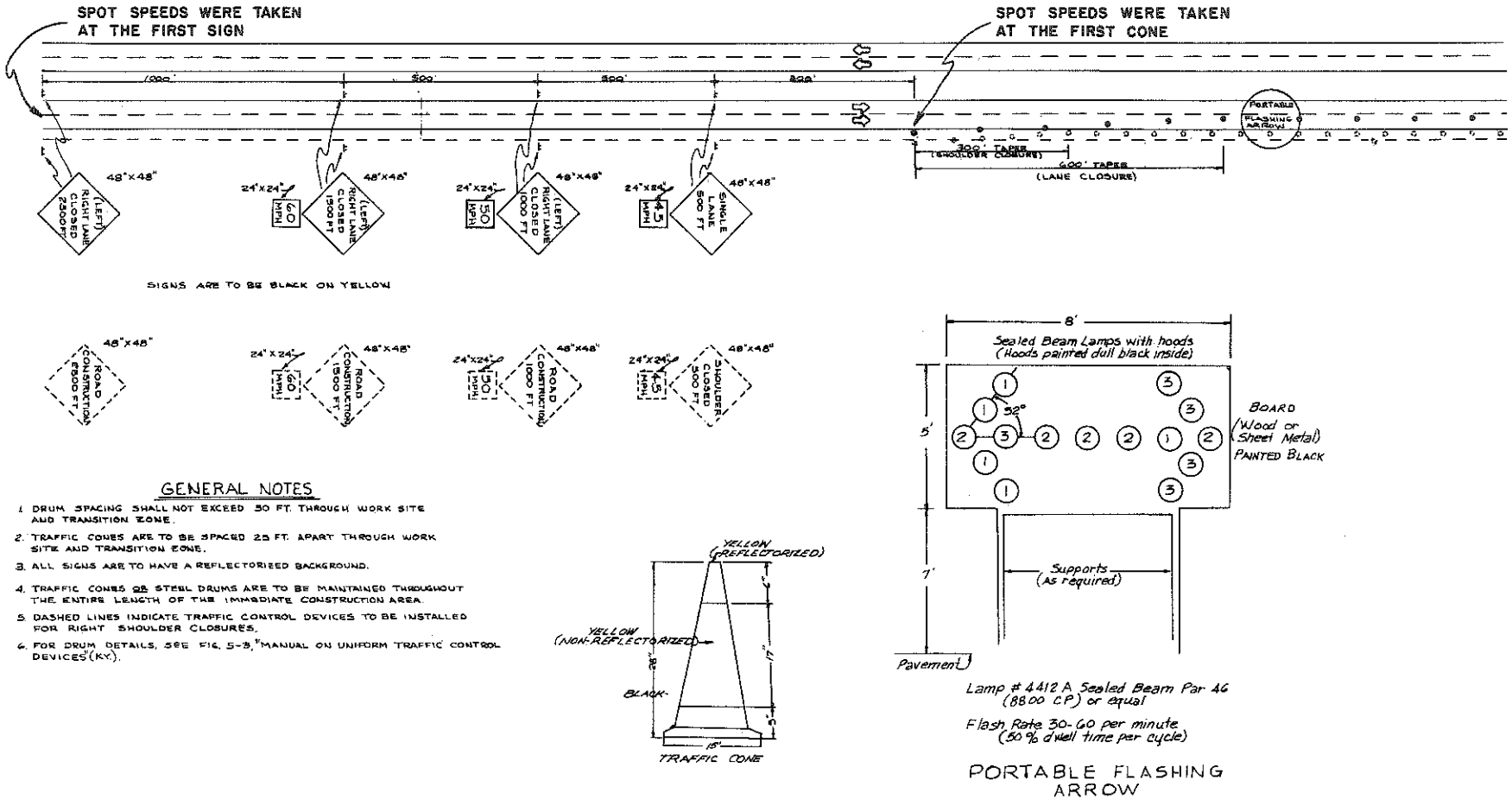


Figure 2. Lane Closure Detail Showing Sign Scheme Used.

were recorded is shown in Figure 3.

TRAFFIC CONFLICTS

Traffic conflicts were categorized and defined as follows:

Abnormal Brake Application - A very rapid deceleration causing "dipping" of 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 (see sample data sheet, Figure 4). 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-foot intervals.

TURN SIGNALS

Turn signals were counted and converted into percent of total lane changes. Originally, it was intended to return to a site after the lane was reopened to count turn signals under normal conditions and also to measure spot speeds one-half mile ahead of the lane closure site. A sampling of these "secondary studies" was made; but, for various reasons, these studies were discontinued.

At all times, observers attempted to be inconspicuous to the motorist (Figure 5). Tables 1 through 4 summarize these data.

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 6. 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 7. 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 *(3)*.

Auto speeds at the first cone (Table 5) were approximately 6 to 10 miles per hour higher than the advisory speed limit: that is, 45 miles per hour, posted 500 feet before the first cone. The mean, 85th percentile speed of all cars at the first cone was a little over 59 miles per hour. Table 7 shows all mean, 85th percentile speeds.

TRAFFIC CONFLICTS

Figures 8 and 9 show conflicts per hundred vehicles at each site (Phase 2) for right and left lane closures, respectively. From Figures 8 and 9, 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 are 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 *(4)*, 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

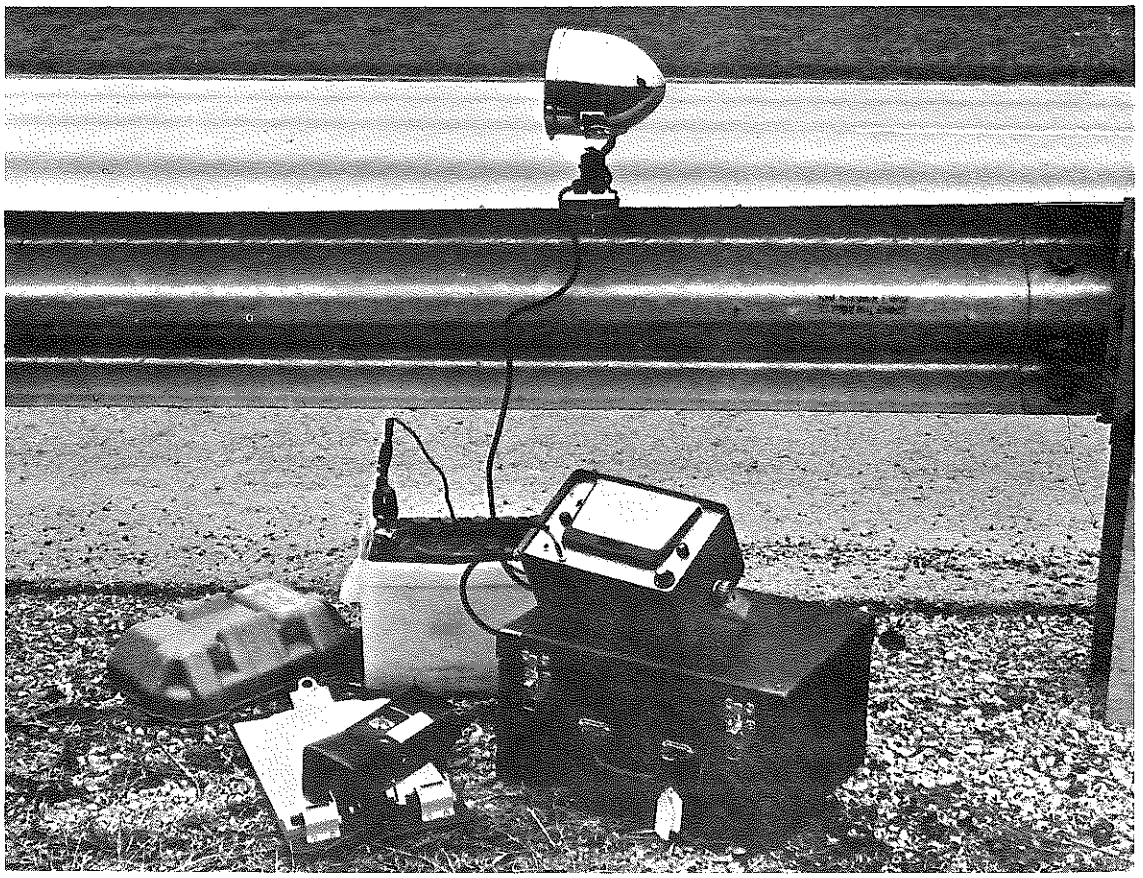


Figure 3. Typical Radar Installation for Spot Speeds Taken at the First Sign.

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
DIVISION OF RESEARCH

KYHPR 61 DATA SHEET

COUNTY	ROUTE NO.	MILE POST	MPH	DATE
SHELBY	I 64	45	70	8-25-71

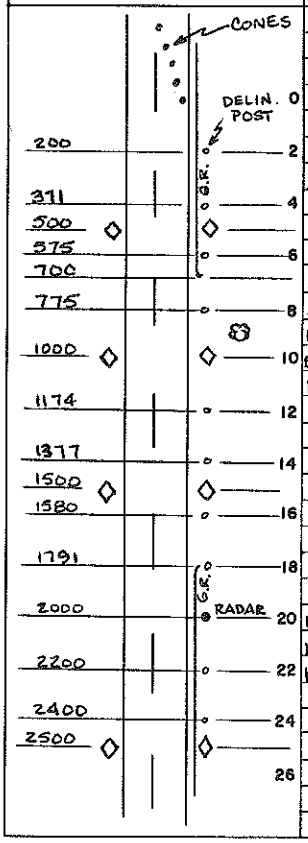
TIME	TO	DAY	WEATHER	N.S.(E)W. BOUND
10:55	11:55	WED.	SUNNY	

DESIGN FEATURES	FLAGMAN	SIGN HEIGHT
STRAIGHT, LEVEL TO 1000' SIGN; THEN CURVE LEFT	YES	

PAVEMENT CONDITIONS	LANE CLOSED	SIGN COLOR
DRY, GOOD	RIGHT	YELLOW

S.D. TO FIRST SIGN	VOLUME	AUTO	TRUCK
0.4 MILE	427	345	82

MERGING MANEUVERS



REFERENCE FROM WORK	DISTANCE SITE	AUTOS	TRUCKS	TOTAL
				—
	0	II	I	3
200	2	III		3
		IIII		4
311	4	I		1
500		I	I	2
575	6	III		3
700		⧸⧸⧸	I	6
775	8	⧸⧸⧸ ⧸⧸⧸		10
		⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸ III	III	21
1000	10	⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸	IIII	29
		⧸⧸⧸ ⧸⧸⧸ I	II	13
1174	12	⧸⧸⧸ ⧸⧸⧸ II	II	14
		⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸ IIII	III	22
1377	14	⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸ II	IIII	21
1500		⧸⧸⧸ ⧸⧸⧸	II	12
1580	16	⧸⧸⧸ II	IIII	11
		⧸⧸⧸ IIII	II	11
1791	18	⧸⧸⧸ ⧸⧸⧸ I	I	12
		⧸⧸⧸ ⧸⧸⧸ I	⧸⧸⧸	16
2000	20	⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸	I	26
		⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸	⧸⧸⧸	30
2200	22	⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸	⧸⧸⧸ II	27
		⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸	⧸⧸⧸	20
2400	24	⧸⧸⧸ ⧸⧸⧸ III	⧸⧸⧸ IIII	22
2500		⧸⧸⧸ ⧸⧸⧸	⧸⧸⧸ IIII	19
	26			

TRAFFIC CONFLICTS

ABNORMAL BRAKE APPL.	FORCED MERGES	COMPLETE STOPS
⧸⧸⧸ I	II	

TURN SIGNALS

NORMAL COND.		DURING MAINT.	
LANE CHG.	TURN SIG.	LANE CHG.	TURN SIG.
		SAME AS TOTAL MERGES	⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸ ⧸⧸⧸ III

OBSERVER D.L.C.

Figure 4. Sample Data Sheet.

Figure 5. Observers Attempted To Be as Inconspicuous to the Motorist as Possible.

TABLE 1

RIGHT LANE CLOSURE DATA
PHASE 1

DATA NUMBER	SIGN COLOR	VOLUME			SIGHT DISTANCE IN MILES TO		DESIGN FEATURES	MEAN SPEEDS* (MPH)		MEAN DECREASE IN SPEED		TRAFFIC CONFLICTS			TOTAL CONFLICTS	TURN SIGNALS	PERCENT MERGES WITH TURN SIGNALS	LENGTH OF SITE† (FEET)	PERCENT MERGES OCCURRING WITHIN ‡				
		CARS	TRUCKS	TOTAL	FIRST SIGN	FLASHING ARROW		CARS	TRUCKS	CARS	TRUCKS	ABNORMAL BRAKE	FORCED MERGE	COMPLETE STOP					0-500'	500'-1000'	1000'-1500'	1500'-2000'	2000'-2500'
R 1.1	Yellow	271	67	338	0.25		Downhill Curve Left	64.67 52.04	57.40 53.27	12.63	4.13	2	1	1	4	44	16.86	2200	25.67	17.63	18.01	36.02	2.68
R 1.2	Yellow	261	86	347	0.85		Uphill Straight	62.65 51.87	58.59 49.88	10.78	8.71	16	3	0	19	46	20.91	1970	9.55	28.64	20.46	41.36	0.00
R 1.3	Yellow	616	64	680	0.60		Uphill Curve Right	66.68 52.82	50.27 42.47	13.86	7.80	44	21	0	65	91	20.87	1925	46.82	15.23	27.50	10.46	0.00
R 1.4	Yellow	395	85	480	0.65	1.15	Uphill Straight	67.47 54.53	66.85 56.50	12.94	10.35	14	9	0	23	68	23.05	2600	12.87	18.38	11.76	17.28	39.71
R 1.5	Yellow	374	59	433	0.65	0.30	Level Curve Right	64.52 56.36	52.35 50.60	8.16	1.75	32	15	0	47	63	20.26	2085	36.01	17.36	12.86	30.87	2.89
R 1.6	Yellow	578	54	632	0.50	0.40	Uphill Curve Right	66.24 55.12	60.20 46.93	11.12	13.27	18	15	0	33	108	27.76	1825	14.40	35.48	41.39	8.74	0.00
R 1.7	Yellow	509	67	576	0.50	0.25	Uphill Straight	66.02 55.36	60.47 49.00	10.66	11.47	28	16	1	45	98	25.39	2000	31.61	24.87	23.32	20.21	0.00
R 1.8	Yellow	421	88	509	0.30	0.55	Down Curve Right Up Straight	70.40 58.96	65.10 54.70	11.44	10.40	14	5	0	19	95	26.03	2958	9.21	16.19	29.21	27.62	17.78
R 1.9	Yellow	540	68	608	0.40	0.70	Straight Level	67.24 53.41	60.00 50.24	13.83	9.76	10	3	0	13	75	27.78	2430	5.56	21.11	26.67	25.56	21.11

* Top speeds were at first sign (2500' sign); bottom speeds were at first traffic cone.
† Distance between first sign and first traffic cone.
‡ Measured from first cone to first sign.

TABLE 2

LEFT LANE CLOSURE DATA
PHASE 1

DATA NUMBER	SIGN COLOR	VOLUME			SIGHT DISTANCE IN MILES TO		DESIGN FEATURES	MEAN SPEEDS* (MPH)		MEAN DECREASE IN SPEED		TRAFFIC CONFLICTS			TOTAL CONFLICTS	TURN SIGNALS	PERCENT MERGES WITH TURN SIGNALS	LENGTH OF SITE† (FEET)	PERCENT MERGES OCCURRING WITHIN ‡				
		CARS	TRUCKS	TOTAL	FIRST SIGN	FLASHING ARROW		CARS	TRUCKS	CARS	TRUCKS	ABNORMAL BRAKE	FORCED MERGE	COMPLETE STOP					0-500'	500'-1000'	1000'-1500'	1500'-2000'	2000'-2500'
L 1.1	Yellow	437	59	496	0.60	1.10	Uphill Straight	67.52 54.52	59.60 45.67	13.00	13.93	15	3	0	18	16	14.29	2500	6.42	11.01	21.10	19.27	42.20
L 1.2	Yellow	539	73	612	0.40	0.50	Up Straight Down Curve Left	65.48 53.92	56.07 53.53	11.56	2.54	5	2	0	7	35	25.00	3015	11.00	19.00	21.00	22.00	27.00
L 1.3	Yellow	513	87	600	0.25	0.35	Down Straight Curve Left	67.08 60.04	56.60 56.65	7.04	+0.05	11	3	0	14	25	13.37	2238	20.86	13.90	27.81	29.41	8.02
L 1.4	Yellow	724	54	778			Downhill Curve Left	66.52 59.60	54.73 53.26	6.92	1.47	12	6	0	18	45	18.44	2238	12.71	18.85	25.82	33.20	9.43
L 1.5	Yellow	532	54	586	0.60	1.00	Up Curve Left Curve Right	70.02 48.12	64.93 47.60	21.90	17.33	13	2	0	15	23	11.44	2571	15.90	24.62	18.46	15.38	25.64
L 1.6	Yellow	480	63	543	0.40	0.40	Up Straight Down Curve Left	65.60 54.52	60.50 53.95	11.08	6.55	11	3	0	14	34	20.48	2788	30.07	16.08	13.29	10.49	30.07
L 1.7	Yellow	429	93	522	0.70	0.55	Curve Left Curve Right	67.82 58.48	62.55 55.40	9.34	7.15	4	0	0	4	28	22.05	2181	7.09	13.39	12.60	44.88	22.05
L 1.8	Yellow	218	49	267	0.15		Downhill Curve	64.26 57.42	56.88 51.75	6.84	5.13	6	8	0	14	14	15.91	3200	51.14	19.32	14.77	12.50	2.27
L 1.9	Yellow	699	64	763	0.25	0.55	Downhill Curve Left	68.36 50.24	56.73 47.07	18.12	9.66	14	7	0	21	24	12.50	2260	17.71	16.15	23.96	27.60	14.58

* Top speeds were at first sign (2500' sign); bottom speeds were at first traffic cone.

† Distance between first sign and first traffic cone.

‡ Measured from first cone to first sign.

TABLE 3

RIGHT LANE CLOSURE DATA
PHASE 2

DATA NUMBER	SIGN COLOR	VOLUME			SIGHT DISTANCE IN MILES TO		DESIGN FEATURES	MEAN SPEEDS* (MPH)		MEAN DECREASE IN SPEED		TRAFFIC CONFLICTS			TOTAL CONFLICTS	TURN SIGNALS	PERCENT MERGES WITH TURN SIGNALS	LENGTH OF SITE† (FEET)	0-500'	PERCENT MERGES OCCURRING WITHIN ∓			
		CARS	TRUCKS	TOTAL	FIRST SIGN	FIRST CONE		CARS	TRUCKS	CARS	TRUCKS	ABNORMAL BRAKE	FORCED MERGE	COMPLETE STOP						500'-1000'	1000'-1500'	1500'-2000'	2000'-2500'
R 2.1	Yellow	304	77	381	0.30		Curve Left Straight Level	68.24 52.48	63.80 51.90	15.76	11.90	2	0	0	2	22	6.96	2500	2.22	8.86	16.46	20.25	52.22
R 2.1	Orange	359	62	421	0.30		Curve Left Straight Level	67.32 50.20	63.25 50.20	17.12	13.05	3	2	0	5	32	10.22	2500	2.56	6.07	15.02	21.09	55.27
R 2.2	Yellow	345	82	427	0.40		Straight Level Curve Left	68.52 49.72	63.95 48.90	18.80	15.05	6	2	0	8	38	10.61	2500	3.63	19.27	22.91	21.23	32.96
R 2.2	Orange	322	65	387	0.40		Straight Level Curve Left	69.96 50.24	62.15 51.00	19.72	11.15	3	2	0	5	40	12.46	2500	2.49	19.31	22.12	20.25	35.83
R 2.3	Yellow	165	40	205	0.30		Straight Level Curve Left	65.39 49.06	60.29 44.29	16.33	16.00	5	2	0	7	20	10.36	2500	16.58	30.05	19.17	11.40	22.80
R 2.3	Orange	152	36	188	0.30		Straight Level Curve Left	66.15 52.30	57.75 49.00	13.85	8.75	0	0	0	0	24	14.12	2500	28.24	18.82	21.18	11.77	20.00
R 2.4	Yellow	325	56	381	1.00	0.50	Downhill Curve Left	69.26 50.92	64.00 52.90	18.34	11.10	3	4	0	7	57	18.63	2500	6.54	17.97	16.99	14.05	44.44
R 2.4	Orange	385	66	451	1.00	0.50	Downhill Curve Left	70.02 50.20	63.30 51.45	19.82	11.85	3	3	0	6	58	16.67	2500	7.47	13.51	12.64	13.22	53.16
R 2.5	Yellow	299	61	360	0.55	0.20	Down Curve Left Curve Right	70.38 52.55	66.33 50.87	17.83	15.46	10	3	3	16	22	7.36	2500	20.07	12.04	7.36	12.37	48.16
R 2.5	Orange	360	98	458	0.55	0.20	Down Curve Left Curve Right	67.31 51.00	61.48 45.91	16.31	15.57	8	0	0	8	40	11.98	2500	8.98	13.17	7.78	16.77	53.29
R 2.6	Yellow	214	86	300	0.30	0.20	Down Curve Right Up Down	69.95 51.74	62.48 51.60	18.21	10.88	2	0	2	4	48	22.22	2500	23.15	20.37	12.96	14.81	28.70
R 2.6	Orange	184	68	252	0.30	0.20	Down Curve Right Up Down	70.51 52.49	61.83 51.83	18.02	10.00	2	0	0	2	32	16.49	2500	14.43	22.68	10.31	16.50	35.05
R 2.7	Yellow	148	72	220	0.60	0.20	Up Straight Downhill	70.15 57.19	61.93 50.44	12.96	11.49	2	0	0	2	46	23.71	2500	11.34	18.56	13.40	14.43	42.27
R 2.7	Orange	198	54	252	0.60	0.20	Up Straight Downhill	70.38 57.07	60.75 51.75	13.31	9.00	0	0	0	0	34	18.09	2500	17.02	24.47	17.02	12.77	28.72
R 2.8	Yellow	291	80	371	0.30	0.80	Straight Level	69.90 52.75	62.47 51.53	17.15	10.94	0	1	0	1	42	16.60	2500	1.58	6.72	11.46	22.92	57.31
R 2.8	Orange	291	56	347	0.30	0.80	Straight Level	69.50 52.24	61.49 51.26	17.26	10.23	0	0	0	0	25	10.50	2500	0.84	5.88	8.40	21.43	63.45
R 2.9	Yellow	327	88	415	0.40	0.28	Curve Right Up Straight Down	70.02 50.86	59.81 49.81	19.16	10.00	11	0	2	13	45	14.02	2500	2.49	13.40	18.69	23.05	42.37
R 2.9	Orange	351	93	444	0.40	0.28	Curve Right Up Straight Down	69.68 50.88	60.20 50.07	18.80	10.13	25	1	1	27	41	13.23	2500	2.90	15.48	16.45	18.71	46.45
R 2.10	Yellow	278	44	322	0.85	0.35	Up Straight Down Curve Right	65.47 48.53	48.75 47.25	16.94	1.50	18	0	0	18	24	9.30	2500	12.40	30.23	8.53	7.75	41.09
R 2.10	Orange	286	40	326	0.85	0.35	Up Straight Down Curve Right	66.80 53.53	53.58 47.47	13.27	6.11	4	0	0	4	16	7.48	2500	1.87	17.76	17.76	14.02	48.60

* Top speeds were at first sign (2500' sign); bottom speeds were at first traffic cone.
† Distance between first sign and first traffic cone.
∓ Measured from first cone to first sign.

TABLE 4

LEFT LANE CLOSURE DATA
PHASE 2

DATA NUMBER	SIGN COLOR	VOLUME			SIGHT DISTANCE IN MILES TO		DESIGN FEATURES	MEAN SPEEDS* (MPH)		MEAN DECREASE IN SPEED		TRAFFIC CONFLICTS			TOTAL CONFLICTS	TURN SIGNALS	PERCENT MERGES WITH TURN SIGNALS	LENGTH OF SITE† (FEET)	PERCENT MERGES OCCURRING WITHIN ‡				
		CARS	TRUCKS	TOTAL	FIRST SIGN	FLASHER OR FIRST CONE		CARS	TRUCKS	CARS	TRUCKS	ABNORMAL BRAKE	FORCED MERGE	COMPLETE STOP					0-500'	500'-1000'	1000'-1500'	1500'-2000'	2000'-2500'
L 2.1	Yellow	432	46	478	0.85	0.35	Up Straight Down Curve Right	67.42 53.76	56.21 45.26	13.66	10.95	14	0	0	14	22	18.03	2500	10.00	11.67	10.00	25.00	43.33
L 2.1	Orange	462	40	502	0.85	0.35	Up Straight Down Curve Right	68.40 52.32	58.21 50.63	16.08	7.58	8	2	0	10	24	20.00	2500	3.33	16.67	3.33	18.33	56.67
L 2.2	Yellow	326	46	372	0.85	0.35	Up Straight Down Curve Right	68.64 54.48	57.20 50.73	14.16	6.47	17	1	2	20	10	11.49	2500	5.75	10.34	17.24	22.99	43.68
L 2.2	Orange	334	53	387	0.85	0.35	Up Straight Down Curve Right	69.48 54.08	58.40 52.47	15.40	5.93	15	4	0	19	12	14.46	2500	8.43	7.23	12.05	19.28	53.01
L 2.3	Yellow	664	93	757	0.80		Uphill Straight	69.73 48.00	64.13 50.27	21.73	13.86	6	5	0	11	26	14.05	5000	37.38	5.61	5.61	20.56	30.84
L 2.3	Orange	561	76	637	0.80		Uphill Straight	69.10 54.13	64.32 48.32	14.97	16.00	1	0	0	1	11	7.75	5000	18.31	8.45	11.27	29.58	32.39
L 2.4	Yellow	456	48	504	0.30	0.40	Downhill Curve Left					0	0	0	0	14	7.87	2700	28.38	12.16	13.51	14.86	31.08
L 2.4	Orange	576	58	634	0.30	0.40	Downhill Curve Left	65.00 55.10	54.67 51.53	9.90	3.14	0	0	0	0	29	14.87	2700	12.10	6.37	13.38	24.84	43.31
L 2.5	Yellow	538	54	592	0.30	0.30	Down Straight Up Curve Right	71.26 47.42	65.11 49.67	23.84	15.44	14	4	0	18	44	19.30	2536	9.65	18.42	23.68	20.18	28.07
L 2.5	Orange	532	58	590	0.30	0.30	Down Straight Up Curve Right	69.89 50.94	64.00 50.82	18.95	13.18	4	0	0	4	10	4.76	2536	13.33	20.00	18.10	23.81	24.76
L 2.6	Yellow	340	76	416	0.40	0.90	Straight Level	66.80 51.12	61.95 45.75	15.68	16.20	1	2	0	3	10	9.62	3170	6.76	17.57	37.84	17.57	20.27
L 2.6	Orange	375	57	432	0.40	0.90	Straight Level	68.02 49.60	63.13 48.07	18.42	15.06	2	0	0	2	10	10.99	3170	11.76	22.06	19.12	19.12	27.94
L 2.7	Yellow	556	54	610	0.40	0.40	Level Curve Right Curve Left	66.58 53.16	60.87 44.26	13.42	16.61					12	5.83	2383	14.56	13.59	26.21	17.48	28.16
L 2.7	Orange	600	70	670	0.40	0.40	Level Curve Right Curve Left	67.20 49.33	60.09 49.64	17.87	10.45					34	16.35	2383	12.50	10.58	23.08	26.92	26.92

* Top speeds were at first sign (2500' sign); bottom speeds were at first traffic cone.

† Distance between first sign and first traffic cone.

‡ Measured from first cone to first sign.

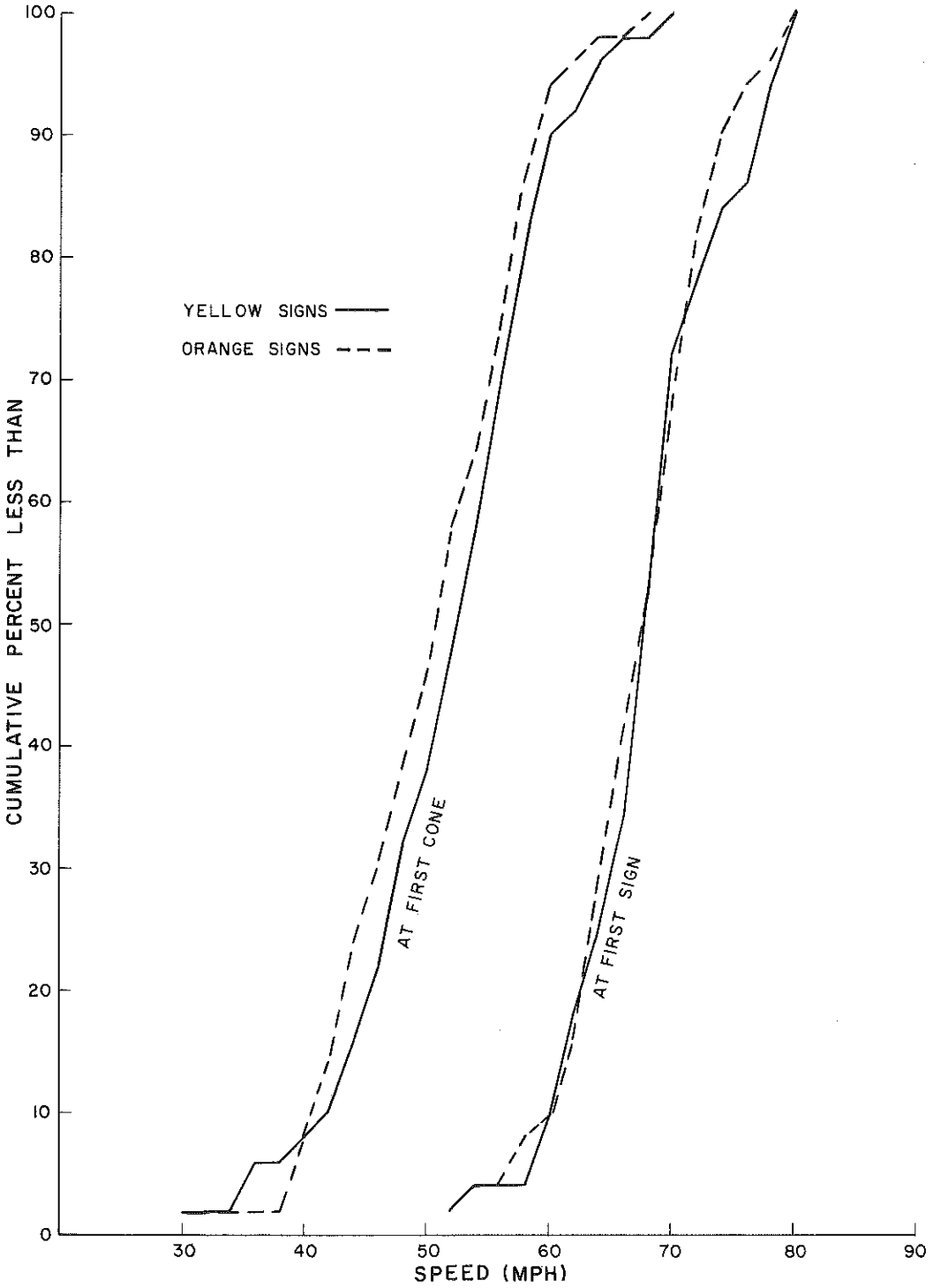


Figure 6. Cumulative Distributions of Speeds at a Site Where Both Sign Colors Were Used.

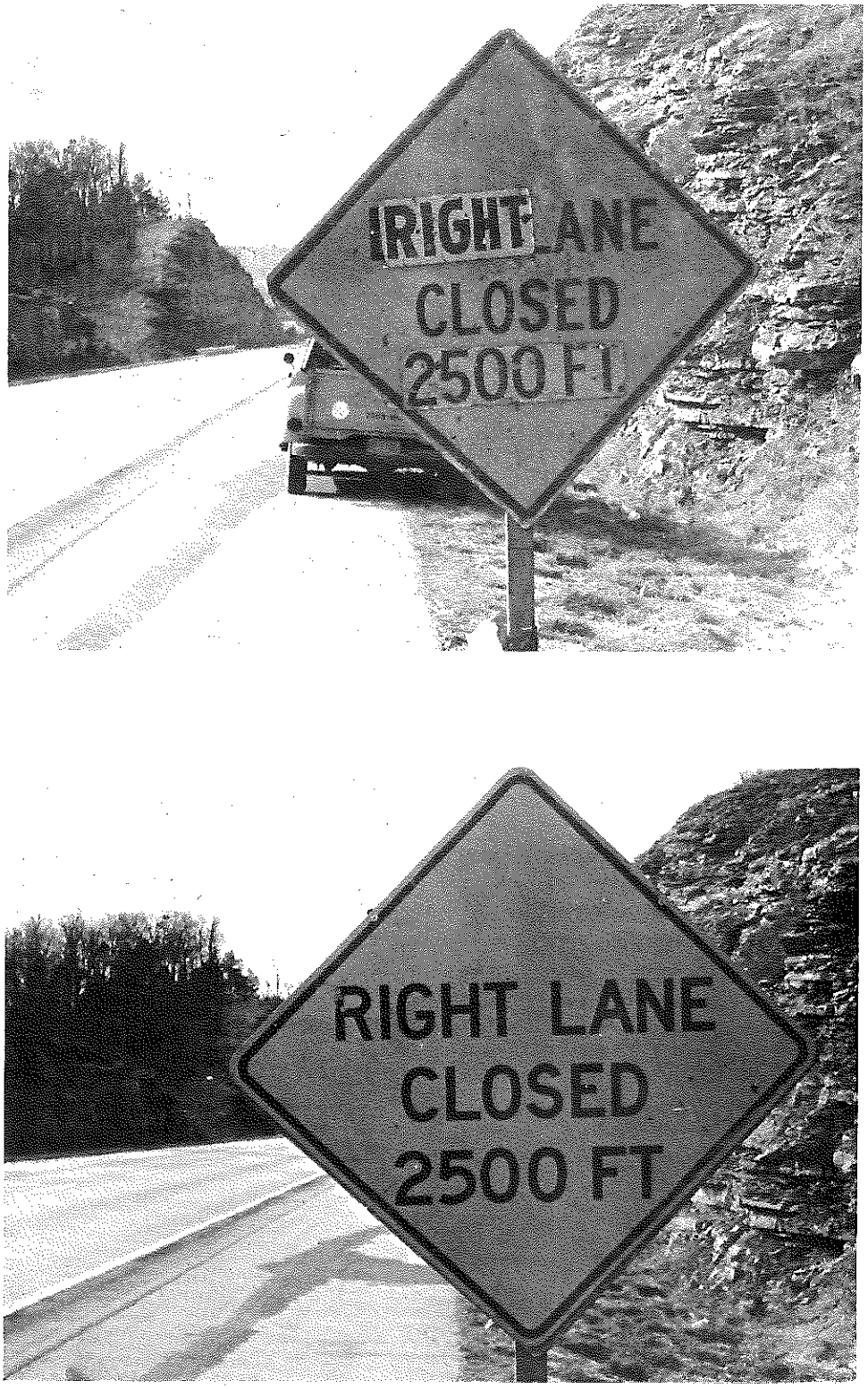


Figure 7. Contractor's Sign (top) as Contrasted with Test Sign.

TABLE 5

AUTO SPEEDS

PHASE	COLOR	LANE CLOSED	MEAN SPEED (MPH) AT FIRST SIGN	MEAN SPEED (MPH) AT FIRST CONE	MEAN DECREASE
1	Yellow	Right	66.21	54.50	11.71
2	Yellow	Right	68.73	51.58	17.15
2	Orange	Right	68.76	52.02	16.74
1	Yellow	Left	66.96	55.21	11.75
2	Yellow	Left	68.41	51.32	17.09
2	Orange	Left	68.16	52.21	15.95

.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 (MPH) AT FIRST SIGN	MEAN SPEED (MPH) AT FIRST CONE	MEAN DECREASE
1	Yellow	Right	59.03	50.40	8.63
2	Yellow	Right	61.38	49.95	11.43
2	Orange	Right	60.58	49.99	10.59
1	Yellow	Left	58.73	51.65	7.08
2	Yellow	Left	60.91	47.66	13.25
2	Orange	Left	60.40	50.21	10.19

.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

			AUTOS		TRUCKS	
PHASE	COLOR	LANE CLOSED	MPH AT FIRST SIGN	MPH AT FIRST CONE	MPH AT FIRST SIGN	MPH AT FIRST CONE
1	Yellow	Right	70.7	60.5	64.6	55.3
2	Yellow	Right	73.3	58.8	65.5	55.6
2	Orange	Right	74.4	58.8	64.4	55.7
1	Yellow	Left	71.6	61.0	63.3	57.1
2	Yellow	Left	73.8	58.4	65.3	53.0
2	Orange	Left	73.4	58.1	64.8	56.1

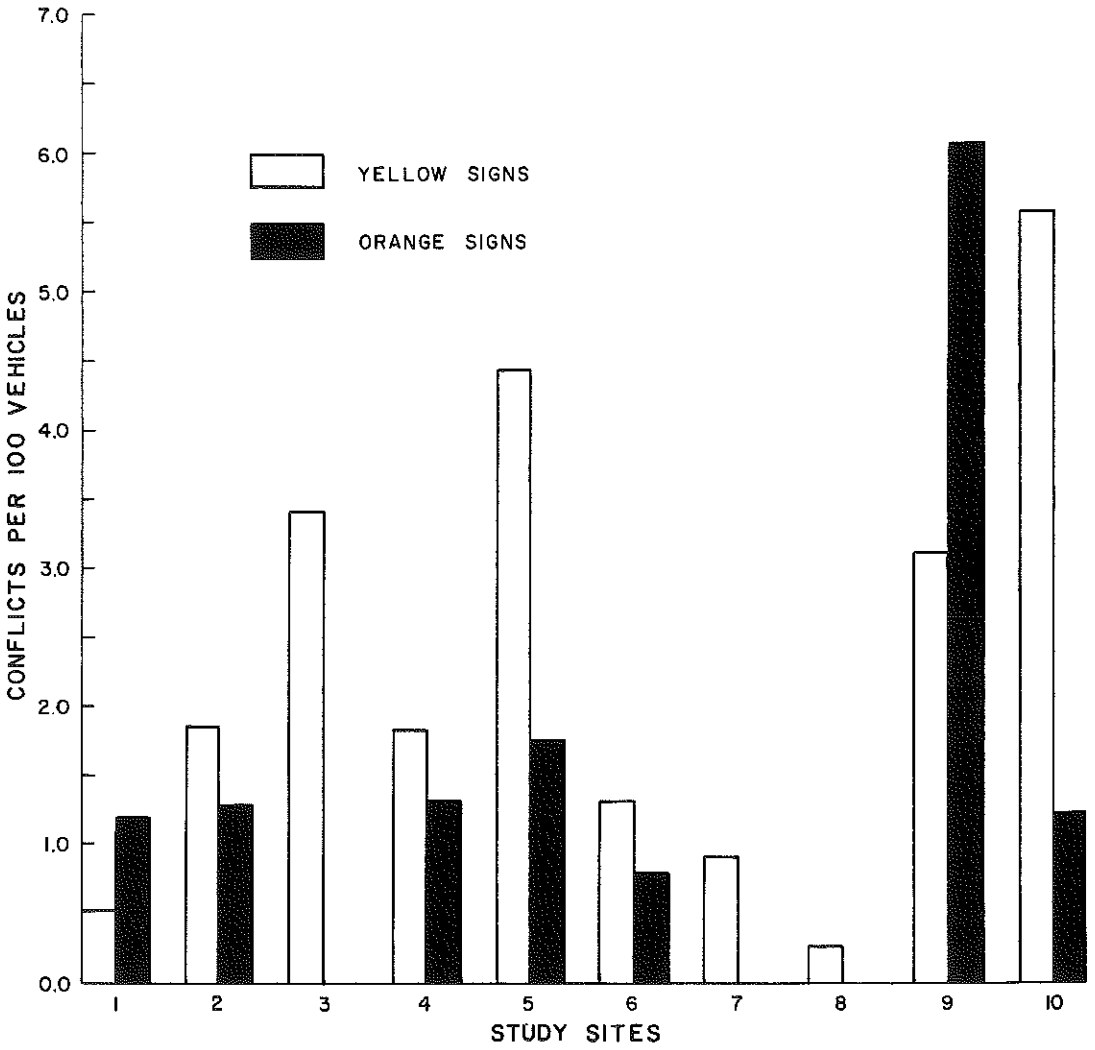


Figure 8. Conflicts per 100 Vehicles at Each Study Site (Right Lane Closures, Phase 2).

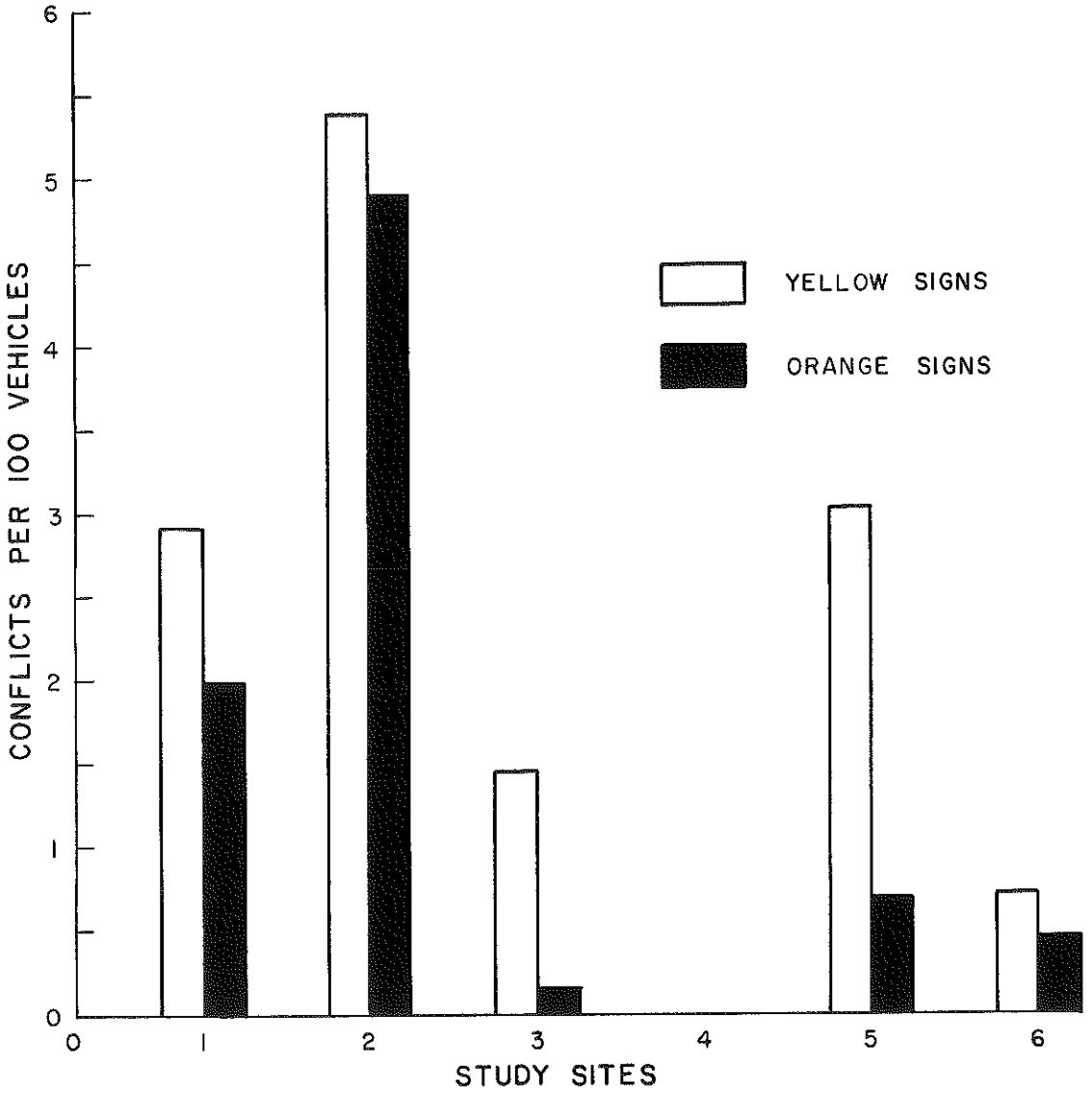


Figure 9. Conflicts per 100 Vehicles at Each Study Site (Left Lane Closures, Phase 2).

TABLE 8

MEAN CONFLICTS PER 100 VEHICLES

PHASE	COLOR	LANE CLOSED	MEAN CONFLICTS/100 VEH
1	Yellow	Right	5.64
2	Yellow	Right	2.33
2	Orange	Right	1.37
1	Yellow	Left	2.59
2	Yellow	Left	2.25
2	Orange	Left	1.37

.01 .001 .20

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 OF THE FIRST TRAFFIC CONE

PHASE	COLOR	LANE CLOSED	PERCENT MERGES WITHIN 500 FT. OF FIRST CONE
1	Yellow	Right	21.30
2	Yellow	Right	10.00
2	Orange	Right	8.68
1	Yellow	Left	19.21
2	Yellow	Left	16.07
2	Orange	Left	11.39

.05 .05 .20

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

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. Hurst, Perchonok, and Seguin *(4)* tested many variables to determine gap acceptability in a merging situation. They computed 27 alternate expressions based on position and velocity information for lead, following, and subject vehicles. This merely illustrates the complex nature of merging maneuvers.

Ideally, if motorists were adequately warned in advance of a lane closure, there would be relatively few merges within the last few hundred feet 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 or two more cars -- that is to say, the more aggressive 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 *(5)*. 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 feet approaching the barricade. Indeed, dangers increased at those sites where the merging in this last 500 feet 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 feet of the barricade. The hourly volumes varied from 188 to 757; sight distances ranged between 0.2 and 0.8 mile; percent trucks varied from 9.5 to 28.7; the length of the site was generally about 2500 feet, but one was 5000 feet in length; 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 gives the percentage of merges occurring within 500 feet of the first cone. This table 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-foot sign and near the first sign (2500 feet). Some distributions showed three peaks. No explanation for these behavioral modes is offered here, but some interesting possibilities may be found in Hutchinson and Roberts' *(6)* work 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 10-12). Orange signs usually lessened the amount of merges nearer the cones and, therefore, in some cases tended to skew the distribution slightly more to the right (see Figures 13-15).

TURN SIGNAL INDICATIONS

Table 10 shows the mean number of turn signal indications for the various site situations. 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 INTERVIEW

A total of 62 drivers were interviewed after they had passed through a lane closure. Sign colors were alternated (2500-foot and 1000-foot signs were yellow; 1500-foot and 500-foot signs were orange) so drivers could make comparisons. Of course, total recall would be most unlikely. The questions and replies are shown in APPENDIX A. 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 No. 6 with one or more complaints. The most common complaint (given six times) was that there is not enough prior notice or advance warning. Two complaints were

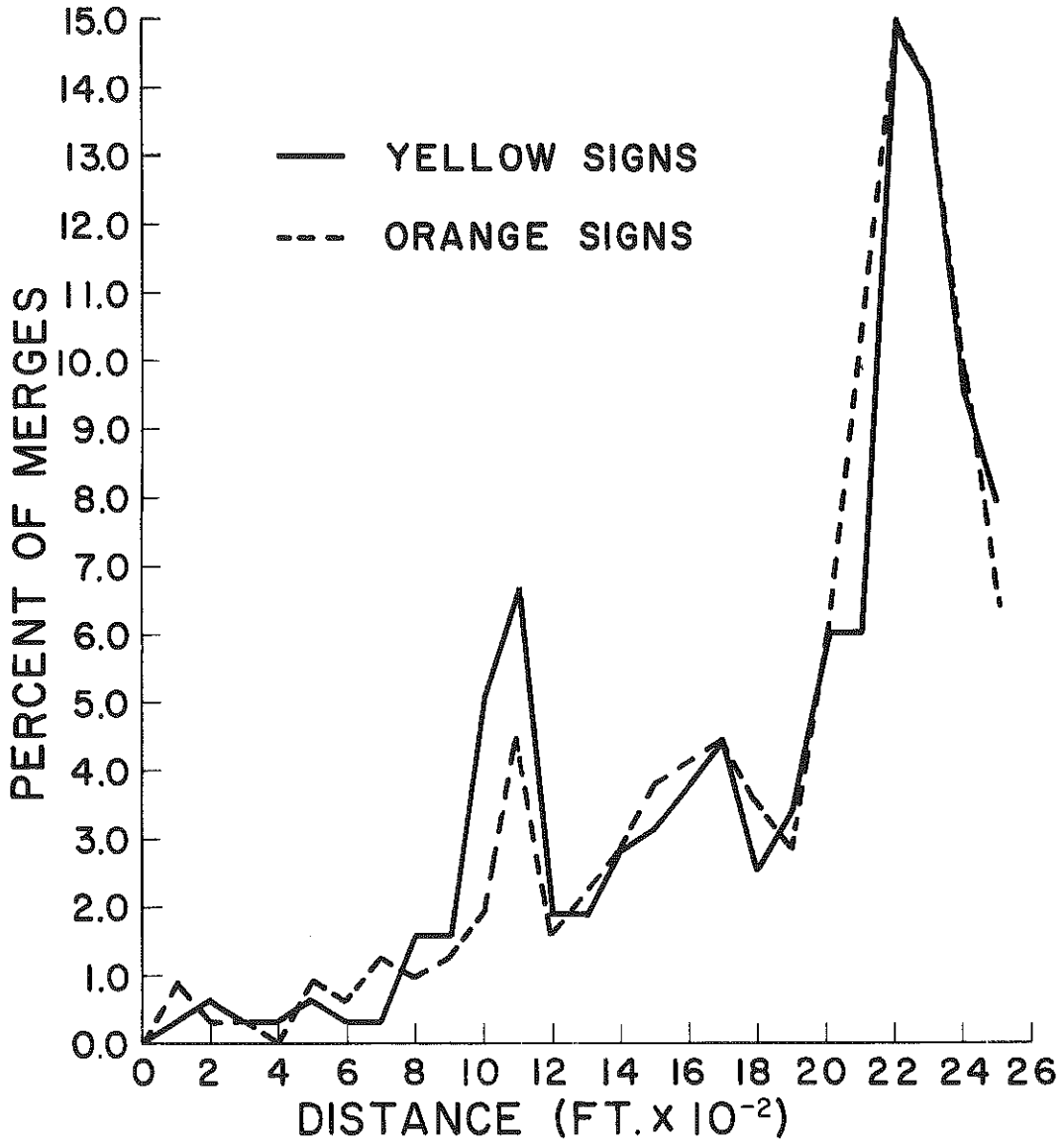


Figure 10. Merge Distributions at Site R 2.1.

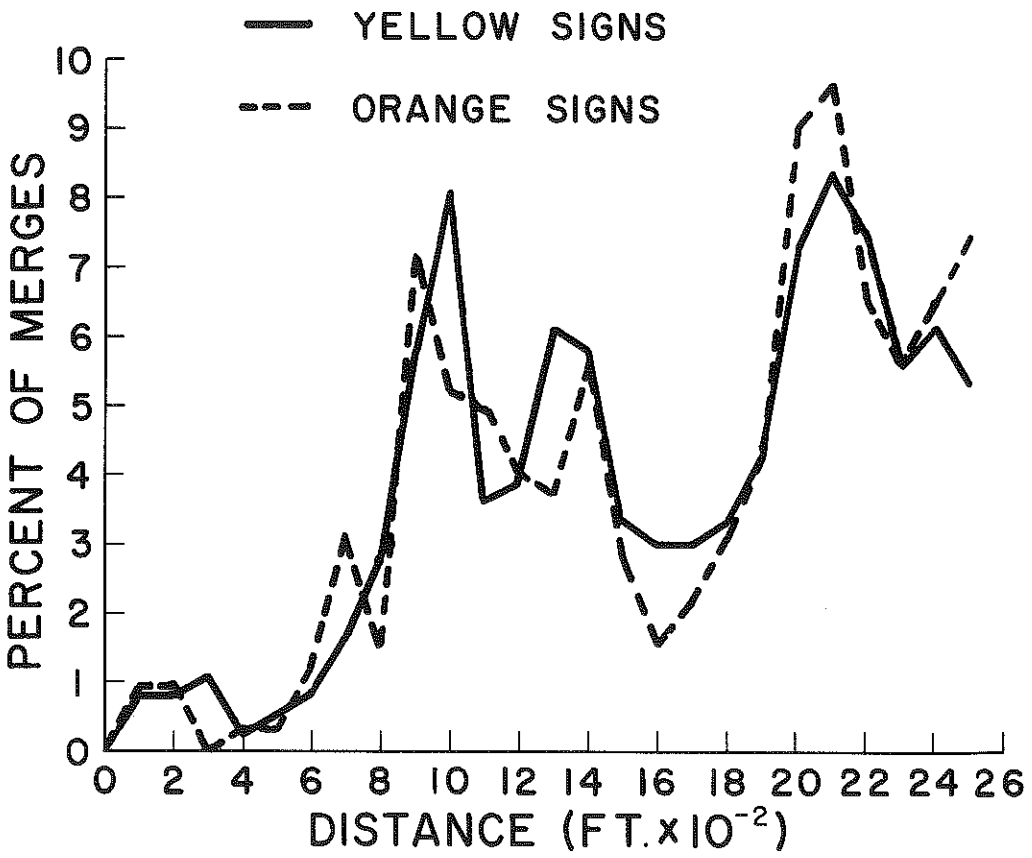


Figure 11. Merge Distributions at Site R 2.2.

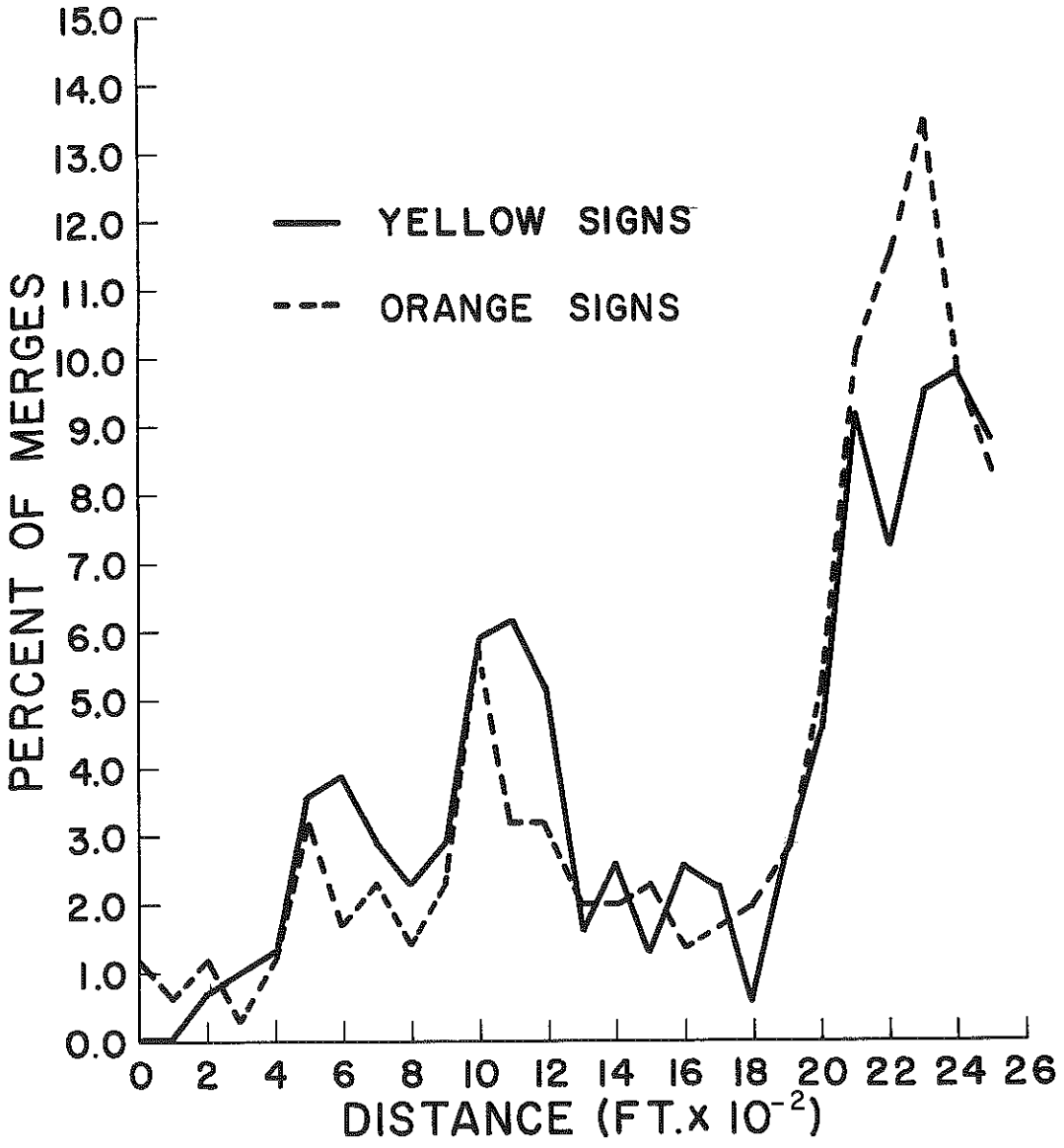


Figure 12. Merge Distributions at Site R 2.4.

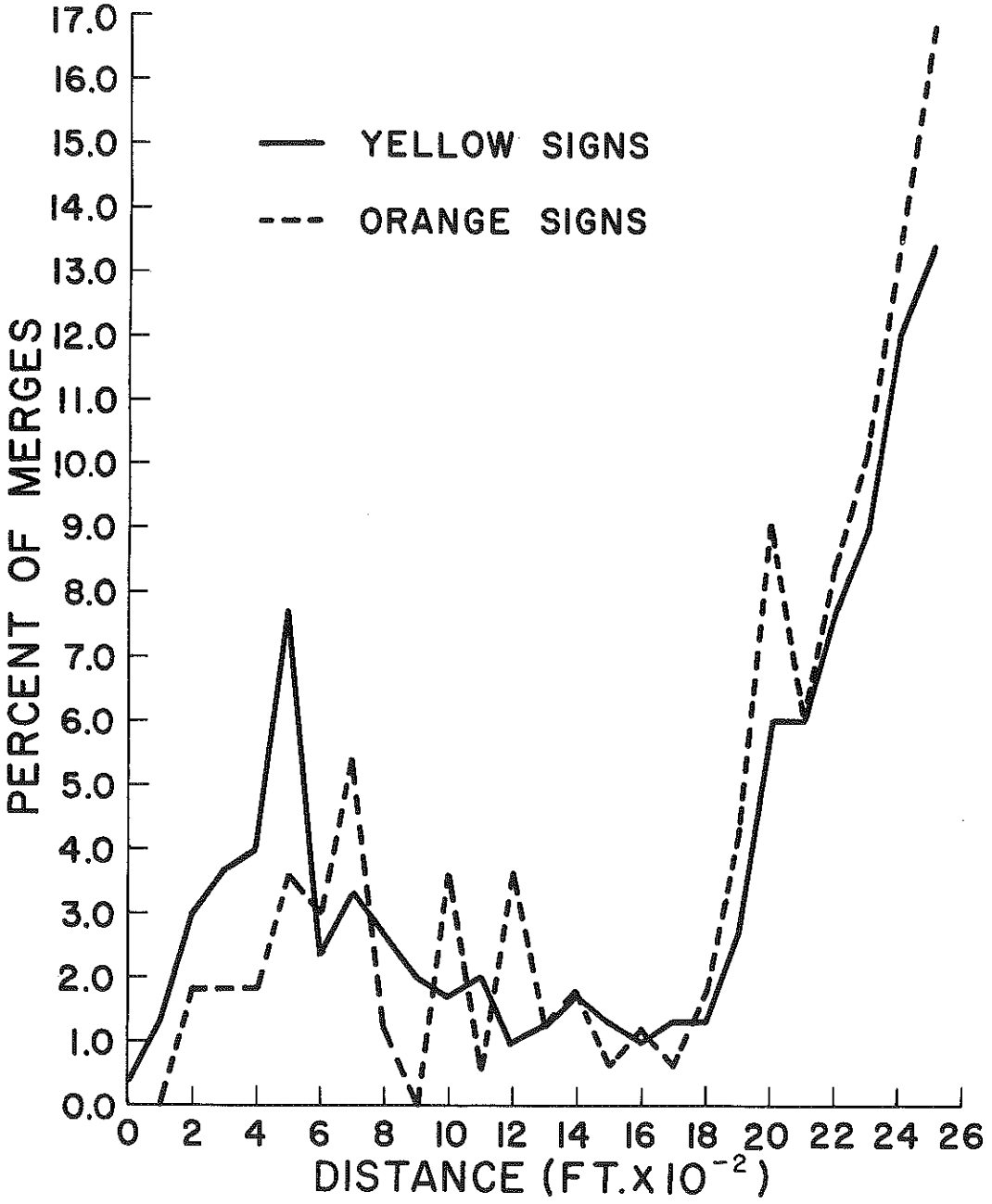


Figure 13. Merge Distributions at Site R 2.5.

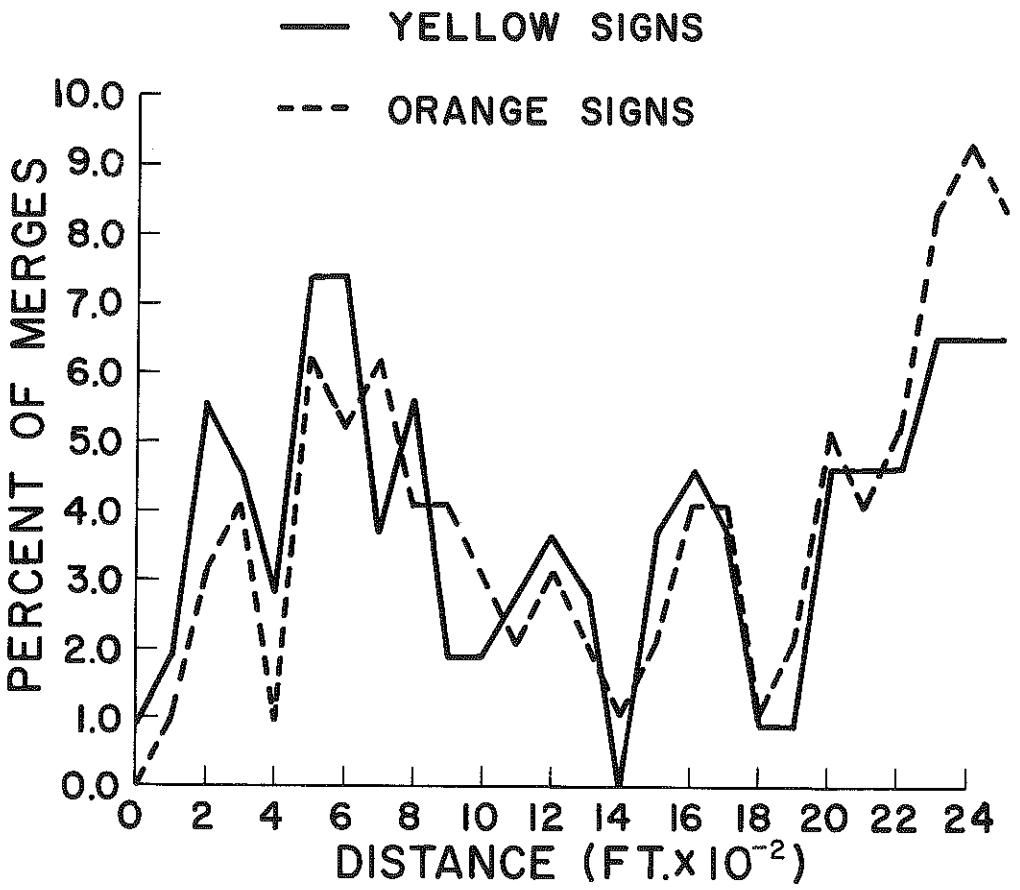


Figure 14. Merge Distributions at Site R 2.6.

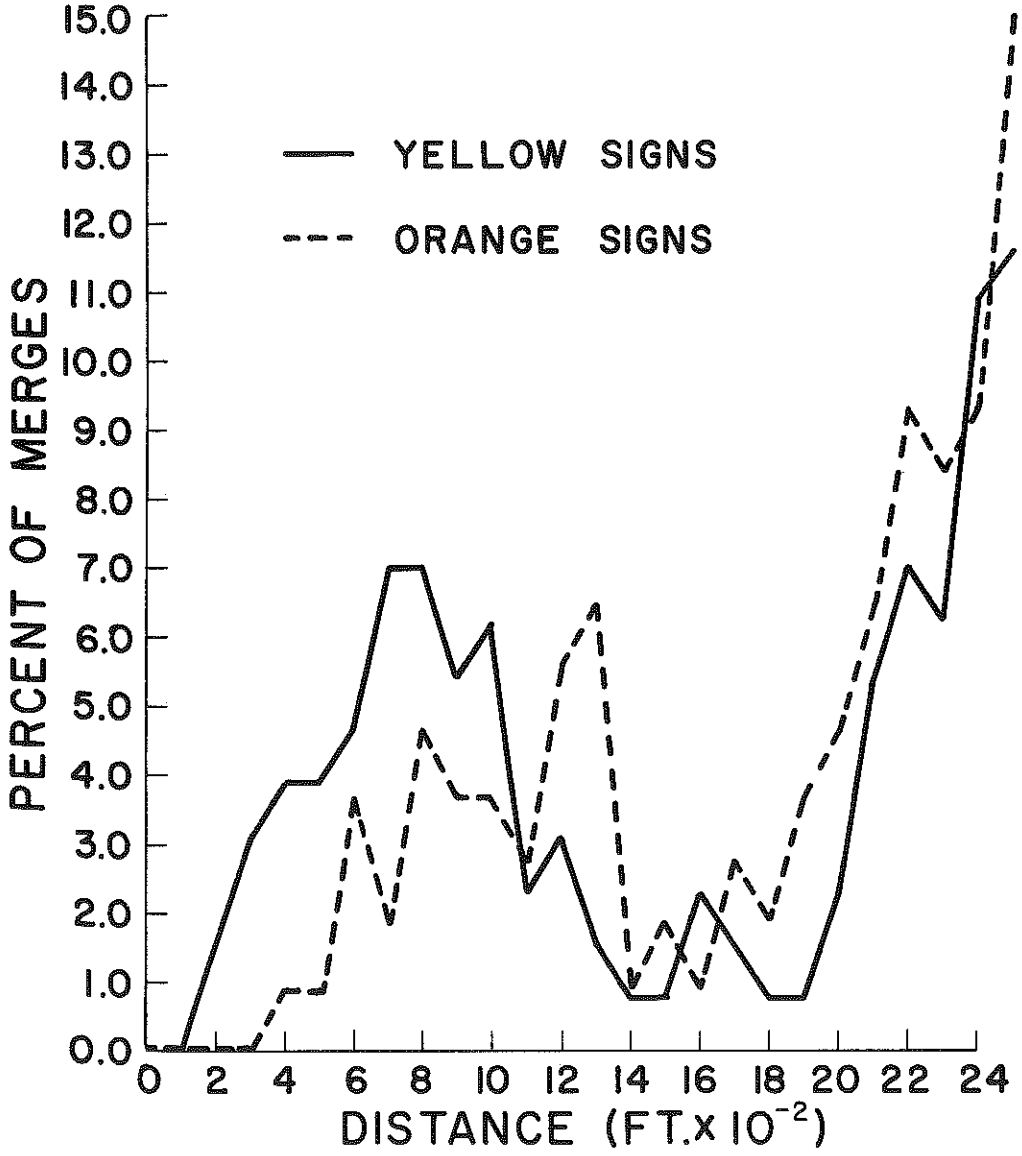


Figure 15. Merge Distributions at Site R 2.10.

TABLE 10

TURN SIGNAL INDICATIONS

PHASE	COLOR	LANE CLOSED	MEAN PERCENT OF MERGES WITH TURN SIGNAL
1	Yellow	Right	23.21
2	Yellow	Right	13.98
2	Orange	Right	13.12
1	Yellow	Left	17.05
2	Yellow	Left	12.31
2	Orange	Left	12.74

.0001 .00001 .10 .10

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

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 No. 8 almost 20 percent of the people interviewed said they wait until they see the actual lane blocked-off 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 of signs, and 4) driver insensitivity.

The adoption of the new AASHO **Manual on Uniform Traffic Control Devices** *(2)* 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. The results of this study tend to substantiate the change in color. Figure 16 shows the signing scheme specified by the new manual *(2).* Kentucky plans to use this scheme supplemented with additional signs 500 and 1500 feet from the first barricade.

An example of deceptive signing is depicted in Figure 17. These signs literally say that there is road construction XXX feet 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 meaning to the road user since there may be no construction visible for several miles. 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" sign (Figure 17), or several signs to this effect, would be adequate for the beginning of an extensive project. On several occassions 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 depicted 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. A simple example of this is shown in Figure 18 *(7, 8).* 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 this site. Figure 19 shows a portable flashing arrow in operation at a lane closure.

The situation presented in Figure 20 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 that they deliberately delayed merging. This is willful disobedience and may be related to the driver attitude which results in speeds 5 to 10 mph 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.

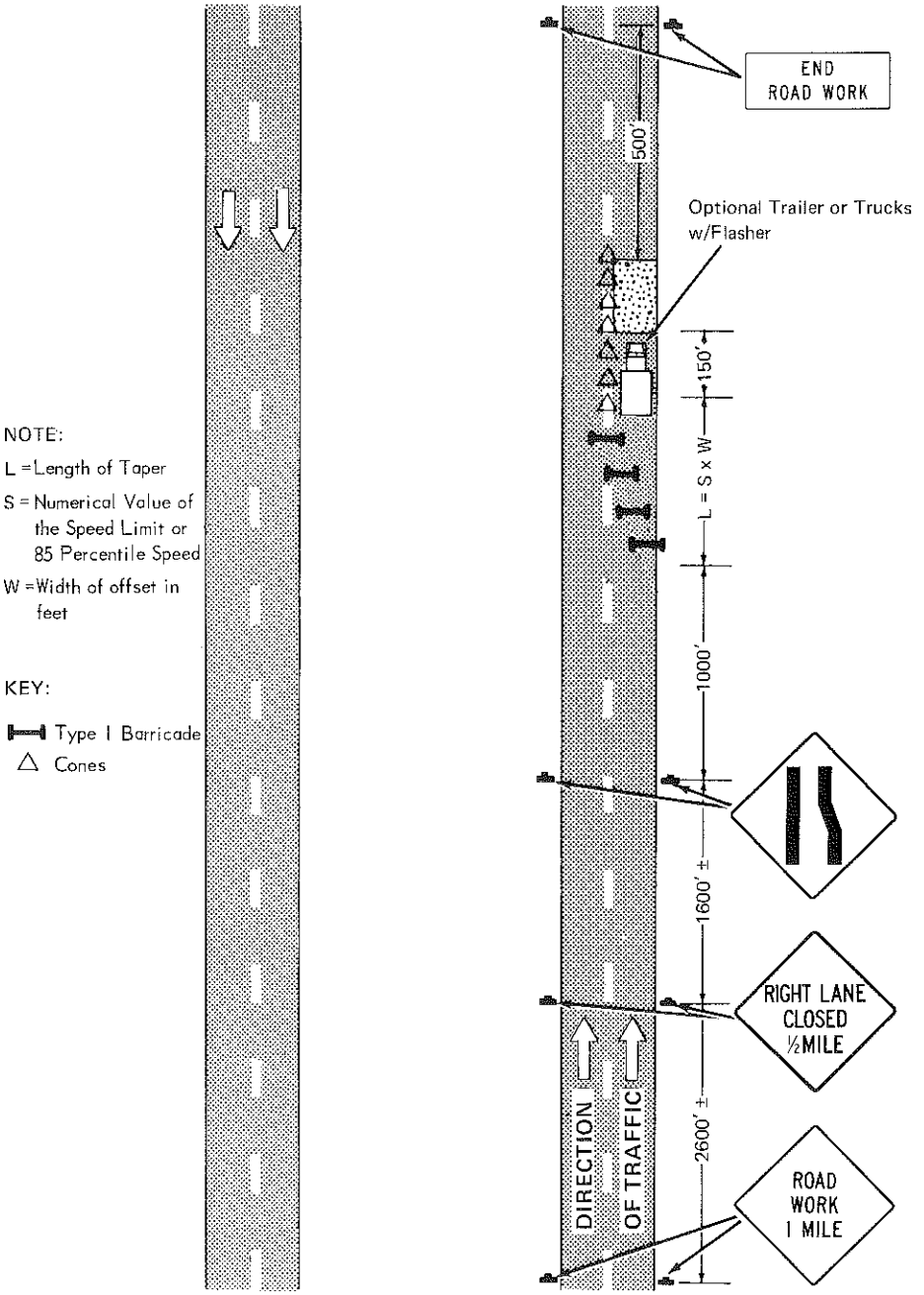


Figure 16. Traffic Control Specified by the New **AASHO Manual on Uniform Traffic Control Devices** *(2)*.

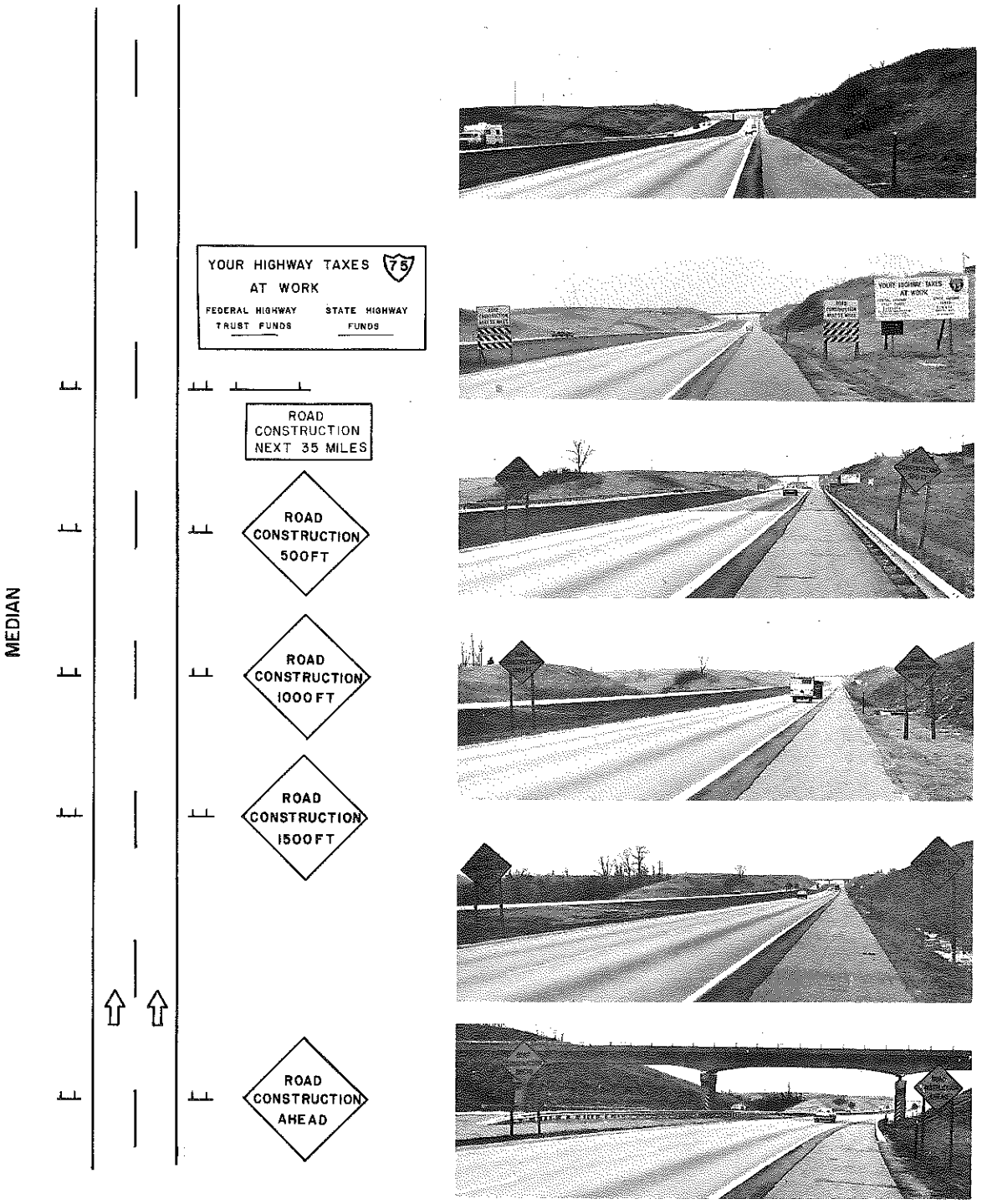
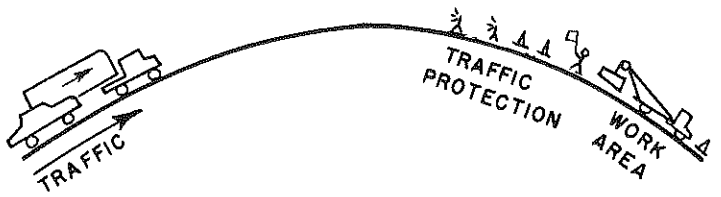


Figure 17. Sign Scheme Preceeding an Extensive Maintenance Project. Top Photo Shows No Maintenance or Construction in Sight.

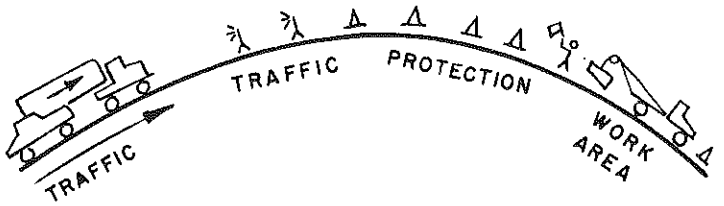
SIGHT DISTANCE

WRONG



TRAFFIC NOT ALERTED UNTIL AFTER CREST OF HILL, MOTORISTS UNAWARE OF OBSTRUCTION AHEAD.

RIGHT



TRAFFIC ALERTED BEFORE CREST OF HILL. MOTORISTS FOREWARNED.

THE SAME PRINCIPLE APPLYS TO CURVES, BRIDGES, FOG, OR ANYTHING ELSE WHICH MAY DENY TIMELY WARNING TO ONCOMING TRAFFIC.

Figure 18. Compensation for Short Sight Distances *(7, 8)*.

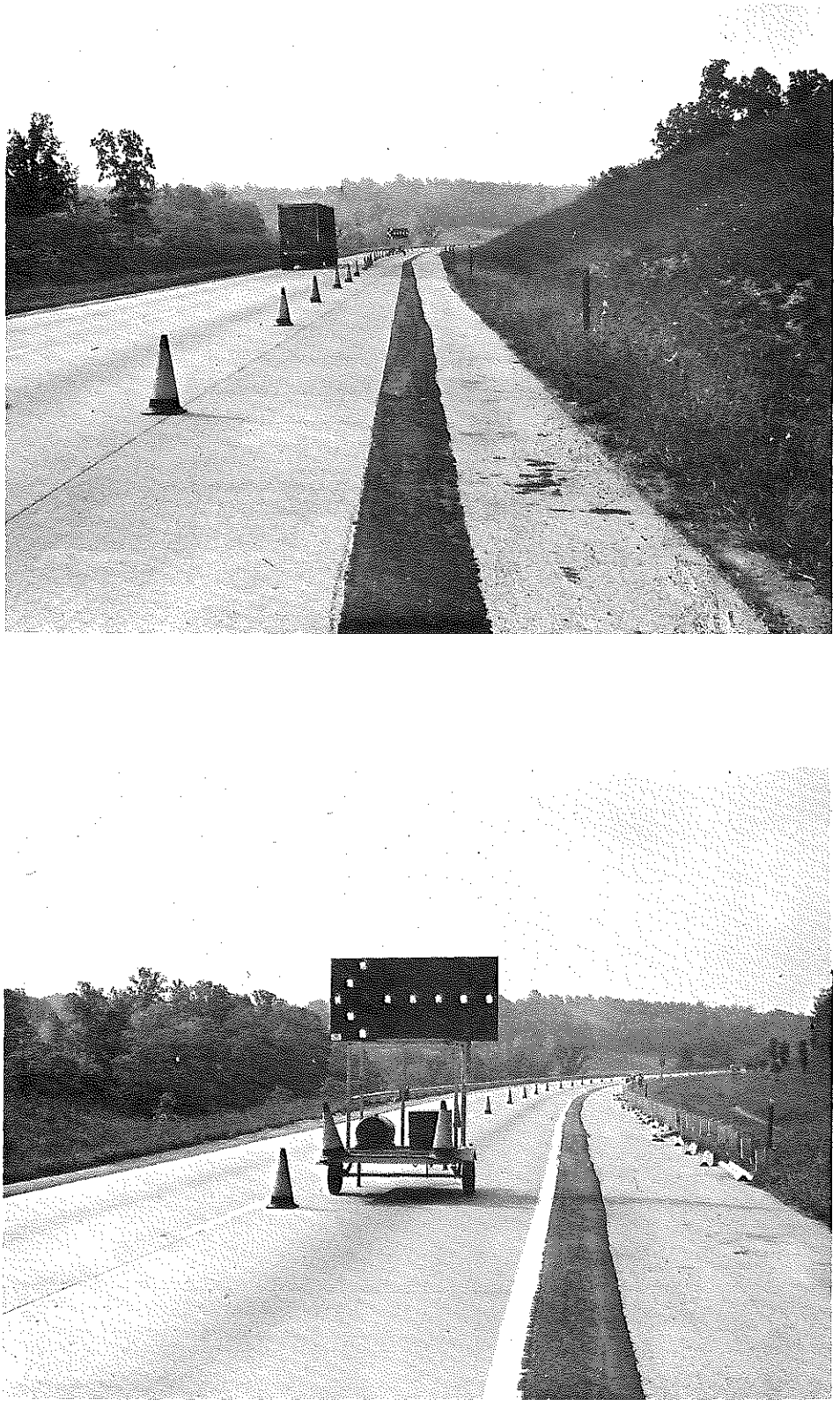


Figure 19. Portable Flashing Arrow in Operation at a Lane Closure.

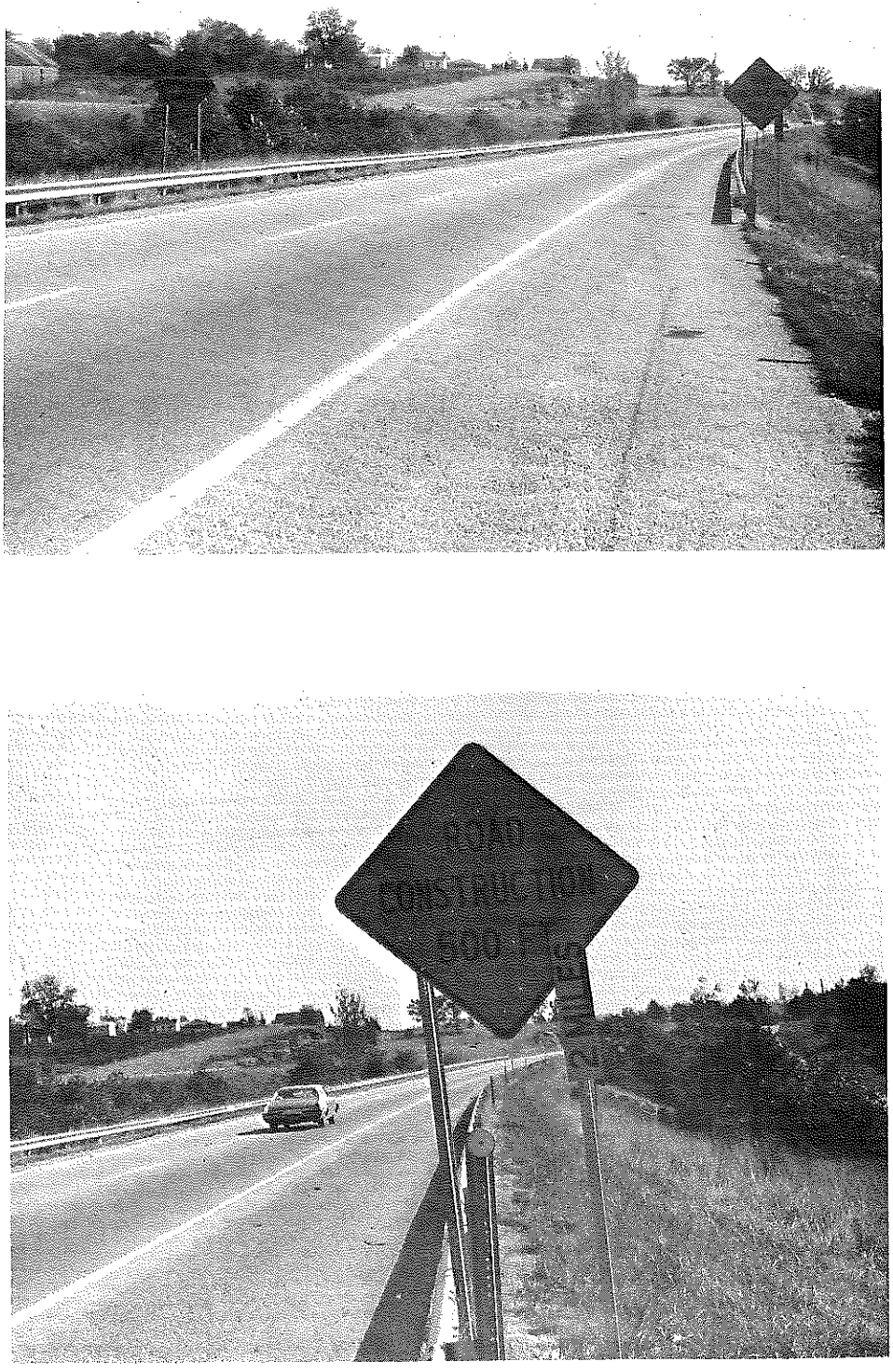


Figure 20. Errors which Cause Confusion and Disrespect for Warning Signs.

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 seem to be needed. Temporary rumble strips, chatter bars, or other disquieting devices may be necessary to adequately impress the message on some drivers.

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APPENDIX A

RESPONSES TO DRIVER INTERVIEW

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

APPENDIX B

STATISTICAL THEORY

When testing hypotheses concerning two means, two tests for statistical significance were applied. These were the so called "z" test and the well known "t" test *(9, 10)*. The hypotheses tested and the formulas for both tests are shown below.

$$H_o : X_1 = X_2 \qquad H_1 : X_1 \neq X_2$$

$$Z = (X_1 - X_2) \,/\, \sqrt{(S_1^2/N_1) + (S_2^2/N_2)}$$

$$H_o : X_1 = X_2 \qquad H_1 : X_1 \neq X_2$$

$$t = (X_1 - X_2) \sqrt{N_1 N_2 (N_1 + N_2 - 2)/(N_1 + N_2)} / \sqrt{(N_1 - 1)\, S_1^2 + (N_2 - 1) S_2^2}$$

For both tests:

X_1 = mean of first sample,
X_2 = mean of second sample,
S_1^2 = variance of first sample,
S_2^2 = variance of second sample,
N_1 = size of first sample, and
N_2 = size of second sample.