TRAFFIC CONTROL FOR MAINTENANCE ON HIGH-SPEED HIGHWAYS

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Observations were made at lane closures on Interstate highways to compare effectiveness of yellow and 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 or at sufficient times to serve as a definitive exploration of such variables as weather, terrain, vertical and horizontal alignment, or level of service.

•MAINTENANCE WORK that 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 judgment, 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 to alternate routes. Public announcements and advice to travelers have proved to be helpful in managing these situations.

This study is 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 or at sufficient times to serve as a definitive exploration of variables such as weather, terrain, vertical and horizontal alignment, or level of service. It was inevitable that data from 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 because of the unnecessary risks created for motorists and consequent liabilities.

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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 (Fig. 1), traffic was observed for 1 hour, new orange signs were superposed, and observations continued for another hour. At sites where other research activities required lane closures, 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 and 2 give test data for right- and left-lane closures in Phase 1. Tables 3 and 4 give test data for right-lane closures in Phase 2, and Tables 5 and 6 give test data for left-lane closures in Phase 2.

Spot Speeds

Radar spot speeds were taken at the first sign at 2,500 ft (760 m) and again at the first traffic cone (Fig. 2). Walkie-talkies were used by the forward radar meter operator to relay identification of each vehicle to the second meter operator. Decreases in speed were used as indicators of effective signing and consequent driver awareness. Greater average decreases in speed were attributed to greater responsiveness to sign messages.

Traffic Conflicts

Traffic conflicts were categorized and defined as follows:

1. Abnormal brake application—a very rapid deceleration that causes "dipping" of vehicle's front end (tire squealing is noted separately).
2. Forced merge—a vehicle that changes lanes directly in front of a following vehicle and causes the following vehicle to apply its brakes; the first vehicle "forces-in" and risks possible contact.
3. 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 100 ft (30 m). For consistency of observation, the point of merging was considered to be where the left front tire crossed the centerline stripe when the vehicle merged to the left and where the right front tire crossed the centerline stripe when the vehicle merged to the right. These observations were later grouped according to percentages occurring in 500-ft (150-m) intervals. Greater percentages of vehicles merging near the traffic cones were considered undesirable and potentially dangerous to motorists as well as to workmen.

Turn Signals

Turn signals were counted and converted into percent of total lane changes. Smaller percentages of turn signal actuations were considered indicative of better signing because this showed less dependency on the turn signal in merging and thus greater driver awareness.

Figure 1. Research personnel positioning new signs over contractor's signs.

Figure 2. Lane closure detail showing sign scheme used.

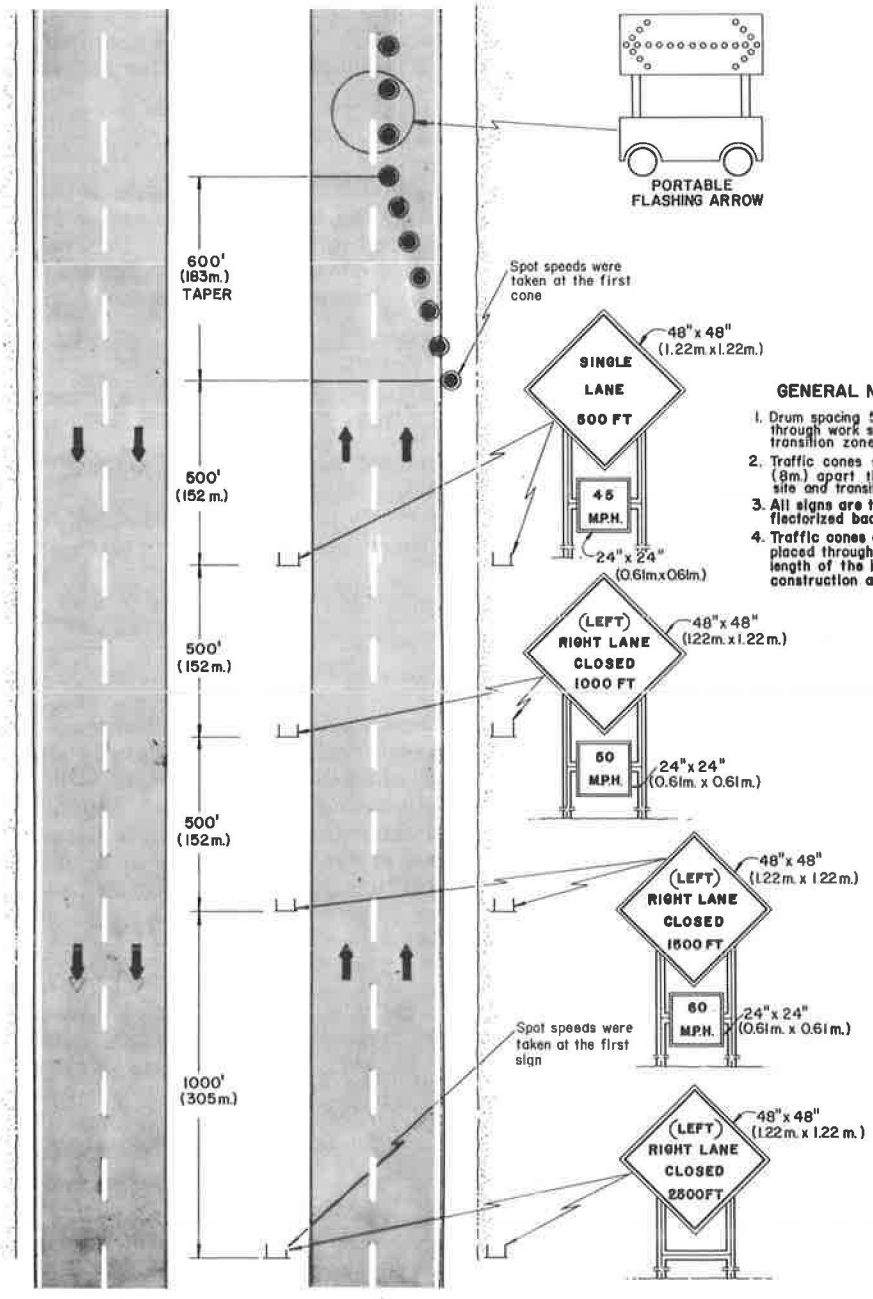

Table 1. Volume, design, and speed data for right- and left-lane closures (Phase 1).

Data Set Number	Volume			Grade	Curve	Sight Distance (miles)		Mean Speed (mph)					
						To First Sign	To First Cone	At First Sign		At First Cone		Decrease	
	Cars	Trucks	Total					Cars	Trucks	Cars	Trucks	Cars	Trucks
R 1.1	271	67	338	-	Lt	0.25		64.6	57.4	52.0	53.3	12.6	4.1
L 1.1	437	59	496	+	Tan	0.60	1.10	67.5	59.6	54.5	45.7	13.0	13.9
R 1.2	261	86	347	+	Tan	0.85		62.7	58.6	51.9	49.9	10.8	8.7
L 1.2	539	73	612	+ to -	Tan to Lt	0.40	0.50	65.5	56.1	53.9	53.5	11.6	2.6
R 1.3	616	64	680	+	Rt	0.60		66.7	50.3	52.8	42.5	13.9	7.8
L 1.3	513	87	600	-	Tan to Lt	0.25	0.35	67.1	56.6	60.0	56.7	7.1	+0.1
R 1.4	395	85	480	+	Tan	0.65	1.15	67.5	66.9	54.5	56.5	13.0	10.4
L 1.4	724	54	778	-	Lt			66.5	54.7	59.6	53.3	6.9	1.4
R 1.5	374	59	433	Level	Rt	0.65	0.30	64.5	52.4	56.4	50.6	8.1	1.8
L 1.5	532	54	586	+	Lt to Rt	0.60	1.00	70.0	64.9	48.1	47.6	21.9	17.3
R 1.6	578	54	632	+	Rt	0.50	0.40	66.2	60.2	55.1	46.9	11.1	13.3
L 1.6	480	63	543	+ to -	Tan to Lt	0.40	0.40	65.6	65.5	54.5	54.0	11.1	11.5
R 1.7	509	67	576	+	Tan	0.50	0.25	66.0	60.5	55.4	49.0	10.6	11.5
L 1.7	429	93	522	Level	Lt to Rt	0.70	0.55	67.8	62.6	58.5	55.4	9.3	7.2
R 1.8	421	88	509	- to +	Rt to Tan	0.30	0.55	70.4	65.1	59.0	54.7	11.4	10.4
L 1.8	218	49	267	-	Tan	0.15		64.3	56.9	57.4	51.8	6.9	5.1
R 1.9	540	68	608	Level	Tan	0.40	0.70	67.2	60.0	53.4	50.2	13.8	9.8
L 1.9	699	64	763	-	Lt	0.25	0.55	68.4	56.7	50.0	47.1	18.1	9.6

Note: 1 mile = 1.6 km; 1 mph = 1.6 km/hour.

Table 2. Conflict and merge data for right- and left-lane closures (Phase 1).

Data Set Number	Conflicts				Turn Signals	Merges With Turn Signals (percent)	Distance Between First Sign and First Cone (ft)	Merges (percent)[a]				
	Abnormal Braking	Forced Merges	Complete Stops	Total				0-500 ft	501-1,000 ft	1,001-1,500 ft	1,501-2,000 ft	2,001-2,500 ft
R 1.1	2	1	1	4	44	16.9	2,200	25.7	17.6	18.0	36.0	2.7
L 1.1	15	3	0	18	16	14.3	2,500	6.4	11.0	21.1	19.3	42.2
R 1.2	16	3	0	19	46	20.9	1,970	9.6	28.6	20.5	41.3	0.0
L 1.2	5	2	0	7	35	25.0	3,015	11.0	19.0	21.0	22.0	27.0
R 1.3	44	21	0	65	91	20.9	1,925	46.8	15.2	27.5	10.5	0.0
L 1.3	11	3	0	14	25	13.4	2,238	20.9	13.9	27.8	29.4	8.0
R 1.4	14	9	0	23	68	23.1	2,600	12.9	18.4	11.7	17.3	39.7
L 1.4	12	6	0	18	45	18.4	2,238	12.7	18.9	25.8	33.2	9.4
R 1.5	32	15	0	47	63	20.3	2,085	36.0	17.4	12.9	30.8	2.9
L 1.5	13	2	0	15	23	11.4	2,571	15.9	24.6	18.5	15.4	25.6
R 1.6	18	15	0	33	108	27.8	1,825	14.4	35.5	41.4	8.7	0.0
L 1.6	11	3	0	14	34	20.5	2,788	30.1	16.1	13.3	10.5	30.1
R 1.7	28	16	1	45	98	25.4	2,000	31.6	24.9	23.3	20.2	0.0
L 1.7	4	0	0	4	28	22.1	2,181	7.1	13.4	12.6	44.9	22.1
R 1.8	14	5	0	19	95	26.0	2,958	9.2	16.2	29.2	27.6	17.8
L 1.8	6	8	0	14	14	15.9	3,200	51.1	19.3	14.8	12.5	2.3
R 1.9	10	3	0	13	75	27.8	2,430	5.6	21.1	26.7	25.5	21.1
L 1.9	14	7	0	21	24	12.5	2,260	17.7	16.2	24.0	27.6	14.6

Note: 1 ft = 0.3048 m.
[a]Merges are measured from the first cone back toward the first sign.

Table 3. Volume, design, and speed data for right-lane closures (Phase 2).

Data Set Number	Sign Color	Volume			Grade	Curve	Sight Distance (miles)		Mean Speed (mph)					
							To First Sign	To First Cone	At First Sign		At First Cone		Decrease	
		Cars	Trucks	Total					Cars	Trucks	Cars	Trucks	Cars	Trucks
R 2.1	Yellow	304	77	381	Level	Lt	0.30		68.2	63.8	52.5	51.9	15.7	11.9
R 2.1	Orange	359	62	421	Level	Lt	0.30		67.3	63.3	50.2	50.2	17.1	13.1
R 2.2	Yellow	345	82	427	Level	Lt	0.40		68.5	64.0	49.7	48.9	18.8	15.1
R 2.2	Orange	322	65	387	Level	Lt	0.40		70.0	62.2	50.2	51.0	19.8	11.2
R 2.3	Yellow	165	40	205	Level	Lt	0.30		65.4	60.3	49.1	44.3	16.3	16.0
R 2.3	Orange	152	36	188	Level	Lt	0.30		66.2	57.8	52.3	49.0	13.9	8.8
R 2.4	Yellow	325	56	381	-	Lt	1.00	0.50	69.3	64.0	50.9	52.9	18.4	11.1
R 2.4	Orange	385	66	451	-	Lt	1.00	0.50	70.0	63.3	50.2	51.5	19.8	11.8
R 2.5	Yellow	299	61	360	-	Lt to Rt	0.55	0.20	70.4	66.3	52.6	50.9	17.8	15.4
R 2.5	Orange	360	98	458	-	Lt to Rt	0.55	0.20	67.3	61.5	51.0	45.9	16.3	15.6
R 2.6	Yellow	214	86	300	- to +	Rt	0.30	0.20	70.0	62.5	51.7	51.6	18.3	10.9
R 2.6	Orange	184	68	252	- to +	Rt	0.30	0.20	70.5	61.8	52.5	51.8	18.0	10.0
R 2.7	Yellow	148	72	220	+ to -	Tan	0.60	0.20	70.2	61.9	57.2	50.4	13.0	11.5
R 2.7	Orange	198	54	252	+ to -	Tan	0.60	0.20	70.4	60.8	57.1	51.8	13.3	9.0
R 2.8	Yellow	291	80	371	Level	Tan	0.30	0.80	69.9	62.5	52.8	51.5	17.1	11.0
R 2.8	Orange	291	56	347	Level	Tan	0.30	0.80	69.5	61.5	52.2	51.3	17.3	10.2
R 2.9	Yellow	327	88	415	+ to -	Rt to Tan	0.40	0.28	70.0	59.8	50.9	49.8	19.1	10.0
R 2.9	Orange	351	93	444	+ to -	Rt to Tan	0.40	0.29	69.7	60.2	50.9	50.1	18.8	10.1
R 2.10	Yellow	278	44	322	+ to -	Tan to Rt	0.85	0.35	65.5	48.8	48.5	47.3	17.0	1.5
R 2.10	Orange	286	40	326	+ to -	Tan to Rt	0.85	0.35	66.8	53.4	53.5	47.5	13.3	5.9

Note: 1 mile = 1.6 km; 1 mph = 1.6 km/hour.

Table 4. Conflict and merge data for right-lane closures (Phase 2).

Data Set Number	Sign Color	Conflicts: Abnormal Braking	Forced Merges	Complete Stops	Total	Turn Signals	Merges With Turn Signals (percent)	Distance Between First Sign and First Cone (ft)	Merges (percent)[a]: 0-500 ft	501-1,000 ft	1,001-1,500 ft	1,501-2,000 ft	2,001-2,500 ft
R 2.1	Yellow	2	0	0	2	22	7.0	2,500	2.2	8.9	16.5	20.3	52.2
R 2.1	Orange	3	2	0	5	32	10.2	2,500	2.6	6.1	15.0	21.1	55.3
R 2.2	Yellow	6	2	0	8	38	10.6	2,500	3.6	19.3	22.9	21.2	33.0
R 2.2	Orange	3	2	0	5	40	12.5	2,500	2.5	15.3	22.1	20.3	35.8
R 2.3	Yellow	5	2	0	7	20	10.4	2,500	16.6	30.1	19.2	11.4	22.8
R 2.3	Orange	0	0	0	0	24	14.1	2,500	28.2	18.8	21.2	11.8	20.0
R 2.4	Yellow	3	4	0	7	57	18.6	2,500	6.5	18.0	17.0	14.1	44.4
R 2.4	Orange	3	3	0	6	58	16.7	2,500	7.5	13.5	12.6	13.2	53.2
R 2.5	Yellow	10	3	3	16	22	7.4	2,500	20.0	12.0	7.4	12.4	48.2
R 2.5	Orange	8	0	0	8	40	12.0	2,500	9.0	13.2	7.8	16.8	53.3
R 2.6	Yellow	2	0	2	4	48	22.2	2,500	23.2	20.4	13.0	14.8	28.7
R 2.6	Orange	2	0	0	2	32	16.5	2,500	14.4	22.7	10.3	16.5	35.1
R 2.7	Yellow	2	0	0	2	46	23.7	2,500	11.3	18.6	13.4	14.4	42.3
R 2.7	Orange	0	0	0	0	34	18.1	2,500	17.0	24.5	17.0	12.8	28.7
R 2.8	Yellow	0	1	0	1	42	16.6	2,500	1.6	6.7	11.4	22.9	57.3
R 2.8	Orange	0	0	0	0	25	10.5	2,500	0.8	5.9	8.4	21.4	63.5
R 2.9	Yellow	11	0	2	13	45	14.0	2,500	2.5	13.4	18.7	23.1	42.4
R 2.9	Orange	25	1	1	27	41	13.2	2,500	2.9	15.5	16.4	18.7	46.5
R 2.10	Yellow	18	0	0	18	24	9.3	2,500	12.4	30.2	8.5	7.8	41.1
R 2.10	Orange	4	0	0	4	16	7.5	2,500	1.9	17.8	17.8	14.0	48.6

Note: 1 ft = 0.3048 m.
[a]Merges are measured from first cone back toward first sign.

Table 5. Volume, design, and speed data for left-lane closures (Phase 2).

Data Set Numbers	Sign Color	Volume: Cars	Trucks	Total	Grade	Curve	Sight Distance (miles): To First Sign	To First Cone	Mean Speed (mph): At First Sign: Cars	Trucks	At First Cone: Cars	Trucks	Decrease: Cars	Trucks
L 2.1	Yellow	432	46	478	+ to -	Rt	0.85	0.35	67.4	56.2	53.8	45.3	13.6	10.9
L 2.1	Orange	462	40	502	+ to -	Rt	0.85	0.35	68.4	58.2	52.3	50.6	16.1	7.6
L 2.2	Yellow	326	46	372	+ to -	Tan to Rt	0.85	0.35	68.6	57.2	54.5	50.7	14.1	6.5
L 2.2	Orange	334	53	387	+ to -	Tan to Rt	0.85	0.35	69.5	58.4	54.1	52.5	15.4	5.9
L 2.3	Yellow	664	93	757	+	Tan	0.80		69.7	64.1	48.0	50.3	21.7	13.8
L 2.3	Orange	561	76	637	+	Tan	0.80		69.1	64.3	54.1	48.3	15.0	16.0
L 2.4	Yellow	456	48	504	-	Lt	0.30	0.40						
L 2.4	Orange	576	58	634	-	Lt	0.30	0.40	65.0	54.7	55.1	51.5	9.9	3.2
L 2.5	Yellow	538	54	592	- to +	Tan to Rt	0.30	0.30	71.3	65.1	47.4	49.7	23.9	15.4
L 2.5	Orange	532	58	590	- to +	Tan to Rt	0.30	0.30	69.9	64.0	50.9	50.8	19.0	13.2
L 2.6	Yellow	340	76	416	Level	Tan	0.40	0.90	66.8	62.0	51.1	45.8	15.7	16.2
L 2.6	Orange	375	57	432	Level	Tan	0.40	0.90	68.0	63.1	49.6	58.1	18.4	5.0
L 2.7	Yellow	556	54	610	Level	Rt to Lt	0.40	0.40	66.6	60.9	53.2	44.3	13.4	16.6
L 2.7	Orange	600	70	670	Level	Rt to Lt	0.40	0.40	67.2	60.1	49.3	49.6	17.9	10.5

Note: 1 mile = 1.6 km; 1 mph = 1.6 km/hour.

Table 6. Conflict and merge data for left-lane closures (Phase 2).

Data Set Numbers	Sign Color	Conflicts: Abnormal Braking	Forced Merges	Complete Stops	Total	Turn Signals	Merges With Turn Signals (percent)	Distance Between First Sign and First Cone (ft)	Merges (percent)[a]: 0-500 ft	501-1,000 ft	1,001-1,500 ft	1,501-2,000 ft	2,001-2,500 ft
L 2.1	Yellow	14	0	0	4	22	18.0	2,500	10.0	11.7	10.0	25.0	43.3
L 2.1	Orange	8	2	0	10	24	20.0	2,500	3.3	16.7	3.3	18.3	56.7
L 2.2	Yellow	17	1	2	20	10	11.5	2,500	5.8	10.3	17.2	23.0	43.7
L 2.2	Orange	15	4	0	19	12	14.5	2,500	8.4	7.2	12.1	19.3	53.0
L 2.3	Yellow	6	5	0	11	26	14.1	5,000	37.4	5.6	5.6	20.6	30.8
L 2.3	Orange	1	0	0	1	11	7.8	5,000	18.3	8.5	11.3	29.6	32.4
L 2.4	Yellow	0	0	0	0	14	7.9	2,700	28.4	12.2	13.5	14.9	31.1
L 2.4	Orange	0	0	0	0	29	14.9	2,700	12.1	6.4	13.4	24.8	43.3
L 2.5	Yellow	14	4	0	18	44	19.3	2,536	9.7	18.4	23.7	20.2	28.1
L 2.5	Orange	4	0	0	4	10	4.8	2,536	13.3	20.0	18.1	23.8	24.8
L 2.6	Yellow	1	2	0	3	10	9.6	3,170	6.8	17.6	37.8	17.6	20.3
L 2.6	Orange	2	0	0	2	10	11.0	3,170	11.8	22.1	19.1	19.1	27.9
L 2.7	Yellow					12	5.8	2,283	14.5	13.6	26.2	17.5	28.2
L 2.7	Orange					34	16.4	2,383	12.5	10.6	23.1	26.9	26.9

Note: 1 ft = 0.3048 m.
[a]Merges are measured from the first cone back toward the first sign.

FINDINGS

Spot Speeds

Tables 7 and 8 give the mean speeds and mean decreases in speeds. The contractors' signs (Phase 1) were the least effective; drivers did not decrease speed so much as they did with 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 (Fig. 3). The total effect is attributed to differences in quality or condition of the signs. Indeed, the condition of the contractors' signs was inferior to that of the new signs (Fig. 4). Unfortunately, contractors' signs are usually not adequately maintained, especially 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 (9.7 to 16 km/hour) higher than the advisory speed limit [i.e., 45 mph (72 km/hour)] that was 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 (94 km/hour). Table 9 gives all mean 85th percentile speeds.

Traffic Conflicts

Figures 5 and 6 show conflicts per 100 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 10), 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. 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 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 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 flagmen as well as motorists. However, as traffic volume increases and as gaps become smaller, more drivers will be trapped in the closed lane and thereby delay otherwise normal merging and probably cause an increase in forced merging. Also, there are always some drivers who will stay in the closed lane longer than they should just so they can pass one or two more cars [that is, 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 (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 was unusually high (Tables 1-6). 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 in which more than 20 percent of all merges occurred within 500 ft 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 km); percentage of trucks varied from 9.5 to 28.7; and lengths of the sites were generally about 2,500 ft (760 m), but one site was 5,000 ft (1525 m) in length. Yellow signs were in use

Table 7. Automobile mean speeds and mean decreases in speed.

Phase	Sign Color	Lane Closed	Mean Speed (mph) At First Sign	Mean Speed (mph) At First Cone	Mean Decrease (mph)	Level of Significance	
1	Yellow	Right	66.2	54.5	11.7	0.005	0.005
2	Yellow	Right	68.7	51.6	17.1		
2	Orange	Right	68.7	52.0	16.7		
1	Yellow	Left	67.0	55.2	11.8	0.05	0.05
2	Yellow	Left	68.4	51.3	17.1		
2	Orange	Left	68.2	52.2	16.0		

Note: Left- and right-lane closures were not tested together. 1 mph = 1.6 km/hour.

Table 8. Truck mean speeds and mean decreases in speed.

Phase	Sign Color	Lane Closed	Mean Speed (mph) At First Sign	Mean Speed (mph) At First Cone	Mean Decrease (mph)	Level of Significance	
1	Yellow	Right	59.0	50.4	8.6	0.10	0.10
2	Yellow	Right	61.4	50.0	11.4		
2	Orange	Right	60.6	50.0	10.6		
1	Yellow	Left	58.7	51.6	7.1	0.025	
2	Yellow	Left	60.9	47.7	13.2		
2	Orange	Left	60.4	50.2	10.2		

Note: Left- and right-lane closures were not tested together. 1 mph = 1.6 km/hour.

Figure 3. Cumulative distributions of speeds at a site where both sign colors were used.

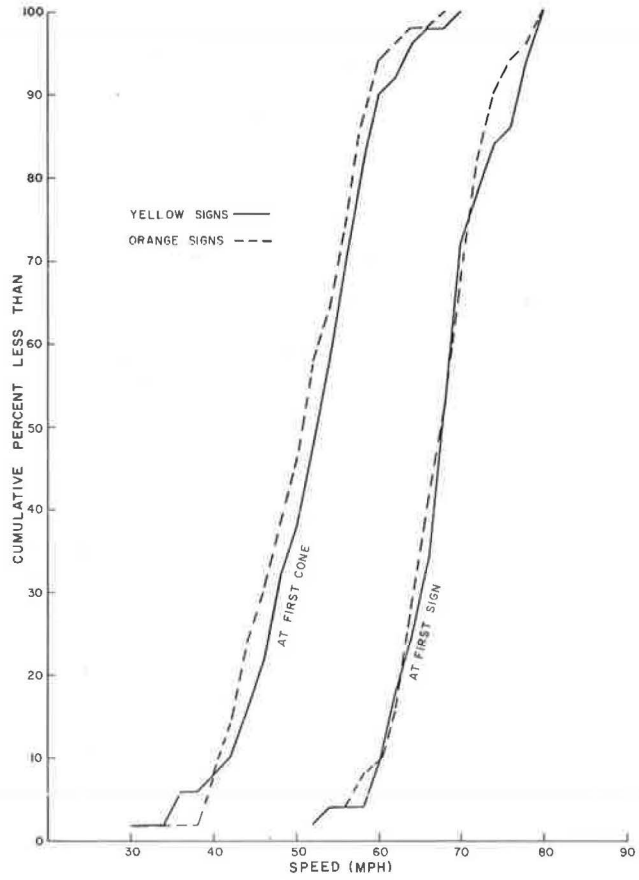

Figure 4. Contractor's sign (left) as contrasted with test sign.

Table 9. Mean 85th percentile speeds.

Phase	Sign Color	Lane Closed	Automobile Speed (mph) At First Sign	Automobile Speed (mph) At First Cone	Truck Speed (mph) At First Sign	Truck Speed (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

Note: Left- and right-lane closures were not tested together. 1 mph = 1.6 km/hour.

Table 10. Mean conflicts per 100 vehicles.

Phase	Color	Lane Closed	Mean Conflicts per 100 Vehicles	Level of Significance
1	Yellow	Right	5.64	0.01
2	Yellow	Right	2.33	0.001
2	Orange	Right	1.37	
1	Yellow	Left	2.59	0.20
2	Yellow	Left	2.25	
2	Orange	Left	1.37	

Note: Left- and right-lane closures were not tested together.

Figure 5. Conflicts per 100 vehicles at each study site (right-lane closures, Phase 2).

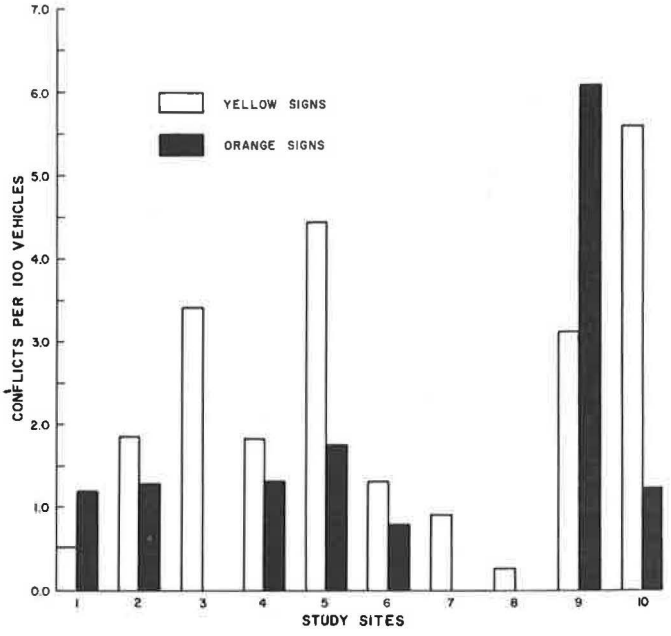

Figure 6. Conflicts per 100 vehicles at each study site (left-lane closures, Phase 2).

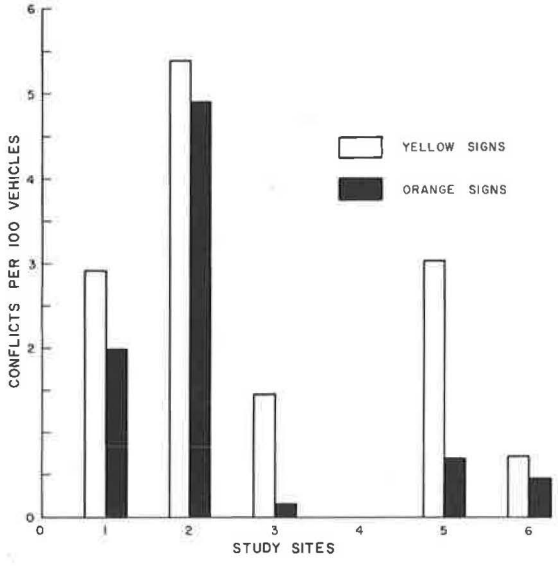

Table 11. Percentage of merges within 500 ft (152 m) of first traffic cone.

Phase	Color	Lane Closed	Merges Within 500 Ft of First Cone	Level of Significance
1	Yellow	Right	21.3	0.05
2	Yellow	Right	10.0	0.05
2	Orange	Right	8.7	
1	Yellow	Left	19.2	0.20
2	Yellow	Left	16.1	
2	Orange	Left	11.4	

Note: Left- and right-lane closures were not tested together. 1 ft = 0.3048 m.

during four of the periods of observation, and orange signs were used during only one. Table 11 gives data that show 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 percentage of merges occurring at each distance. There were peaks in these distributions at or near the 1,000-ft (300-m) sign and near the first sign at 2,500 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 (Figs. 7, 8, 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 (Figs. 10, 11, 12).

Turn Signal Indications

Table 12 gives the mean percentage 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 use 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 so that drivers could make comparisons: 2,500-ft (760-m) and 1,000-ft (300-m) signs were yellow and 1,500-ft (460-m) and 500-ft (150-m) signs were orange. Of course, total recall would be most unlikely. The questions and replies are shown in Figure 13. 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 4 people who said red was more effective were actually referring to the orange signs. Ten people responded to the sixth question 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. Other complaints, each occurring once, were that 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 the eighth question almost 20 percent of the people interviewed said that they wait until they see the actual lane blocked before merging.

DISCUSSION OF FINDINGS

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 (a) short sight distances, (b) high volumes, (c) poor quality signs, and (d) 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 shown in Figure 14. Deceptive signs literally say there is road construction XXX feet ahead. However, the distance is actually measured to the beginning of a project or to the white "Your Highway Taxes at Work" sign, and thus the signs convey a false message to the road user because 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 (Fig. 14), 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

Figure 7. Merge distributions at site R 2.1.

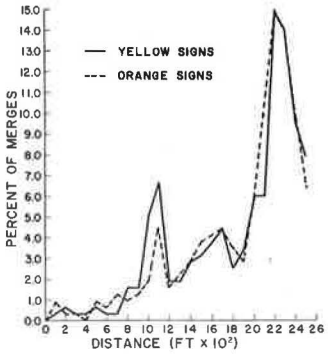

Figure 8. Merge distributions at site R 2.2.

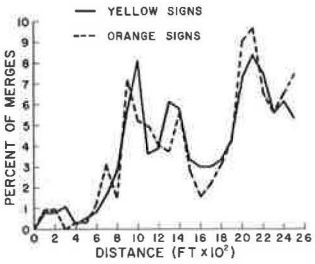

Figure 9. Merge distributions at site R 2.4.

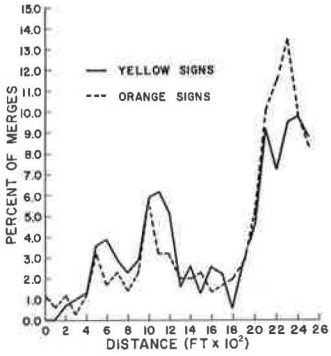

Figure 10. Merge distributions at site R 2.5.

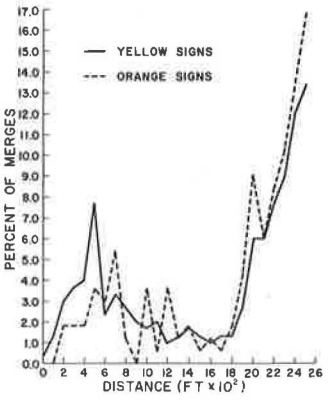

Figure 11. Merge distributions at site R 2.6.

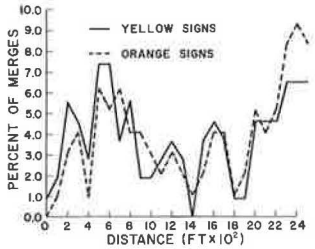

Figure 12. Merge distributions at site R 2.10.

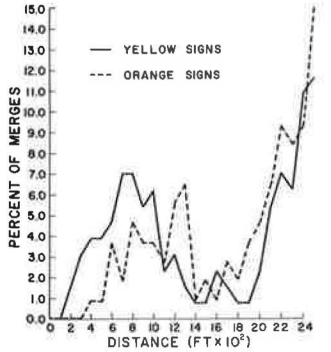

Figure 13. Questions and responses for driver interview.

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

Table 12. Mean percentage of turn signal indications.

Phase	Sign Color	Lane Closed	Mean Percent of Merges With Turn Signal	Level of Significance
1	Yellow	Right	23.2	0.0001
2	Yellow	Right	14.0	0.00001
2	Orange	Right	13.1	
1	Yellow	Right	17.1	0.10
2	Yellow	Left	12.3	0.10
2	Orange	Left	12.7	

Note: Left- and right-lane closures were not tested together.

Figure 14. Sign scheme preceding an extensive maintenance project (top photo shows no maintenance or construction in sight).

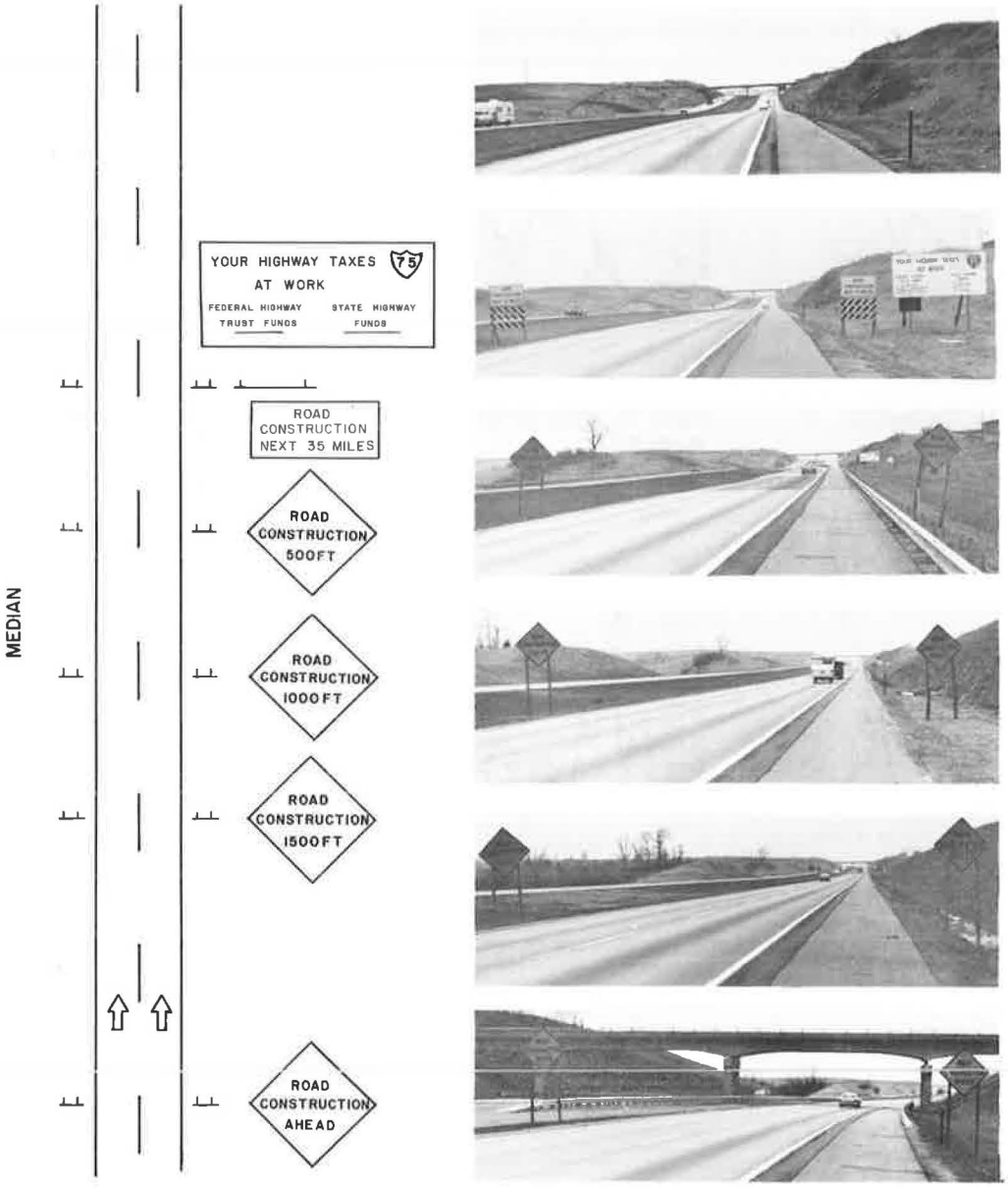

Figure 15. Errors that cause confusion and disrespect for warning signs.

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 shown in Figure 15 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.

Because the new Manual on Uniform Traffic Control Devices 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.) more commonly used 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 ensure that 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 that results in speeds 5 to 10 mph (9.7 to 16 km/hour) 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.
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.

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