HIGHWAY SIGNING FOR SAFETY

by

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Highway Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

Signing that effectively warns the motorist of temporary obstructions on or near a roadway is essential to traffic safety. The general objective of this study was to become familiar with and investigate the suitability of various temporary maintenance signing conditions, with particular attention being given to certain sign combinations and messages, types of warning devices, and a new electronic sign panel for alerting and directing traffic. The effectiveness of the various signing conditions tested was based on observed weaving maneuvers and speeds of vehicles throughout the work area, which was located on a 6-lane rural interstate highway. It is felt that the implementation of the recommendations contained in this report will reduce the accident potential in the operations cited for divided, limited access highways.

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INTRODUCTION

Signing that effectively warns the motorist of temporary obstructions on and near roadways is clearly essential to traffic safety. In the case of highway departments, that are constantly faced with the need to protect both motorists and workers during roadway construction and maintenance operations, the effectiveness of temporary signing is a matter of vital concern. The work reported here is a part of the Virginia Department of Highways' considerable effort in this area of traffic safety.

PURPOSE AND SCOPE

As indicated in the working plan for the study,* the purposes of this research were to:

1. Identify by field observation and testing the accident potential of various highway maintenance and, possibly, construction operations.

2. Identify by data analysis the most specific conditions contributing to accidents at sites of maintenance and construction activities.

3. Determine what can be done to eliminate or reduce the conditions contributing to work site accidents.

4. Review existing rules, regulations, procedures, policies, manuals, and laws governing the protection of persons required to work on or near the roadway, throughout Virginia.

5. Improve public relations through demonstration of the benefits that can be gained by work site protection research.

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* Keller, Charles R., - Working Plan - Highway Signing for Safety, Virginia Highway Research Council (December 1967).

The scope of the project involved the very basic elements of the temporary obstruction problem and provided for an inquiry into the basic situations that now exist in order to determine the present accident potential.

The project was limited to the testing of various devices and signing conditions used for protection of three types of maintenance operations: mowing, shoulder work (fixed), and right lane closure. No special devices were devised for this project, however, various signs with special messages were fabricated. Ten different signing conditions were tested for mowing operations and sixteen conditions for shoulder operations. Forty-one conditions were tested for right lane closure. All testing was conducted during summer months at one site, which was a 6-lane rural interstate highway near Ashland, Virginia. In all cases vehicle speeds, weaving maneuvers, and personal observations were used as criteria for evaluation.

The above restrictions were placed on the project because of the numerous variables involved in the signing arrangements tested.

Because of the many variables considered, each signing condition was tested only once for a 3-4 hour interval. This limitation made evaluation rather difficult since not enough data were obtained to permit a meaningful statistical analysis. Therefore, the analysis consisted of direct comparisons of data sets for the different variables.

PROCEDURE

Maintenance Operations

Typical maintenance operations were selected for the testing of sixty-nine temporary signing conditions. The signing conditions were set up for two "off" roadway operations and one "on" roadway operation, with the maintenance activity being partially simulated in an attempt to test under realistic conditions. The off-roadway maintenance activities were mowing operations and work along the shoulder. In the former, a tractor mower was operated along an 800' length of shoulder to simulate mowing operations; in the latter, a dump truck was parked along the shoulder. "On" roadway activities were represented in all cases by a right lane (lane 1) closure, in which a dump truck was parked along the shoulder, with two wheels partially in the right lane.

Test Site

Since maintenance of the interstate system involves maximum work force exposure to traffic, a 6-lane section of Interstate 95 south of Ashland, Virginia, was chosen as the test site. This tangent section was excellent for the purpose. It has little or no grade, a minimum of roadside interference (signs, ramps, etc.) and moderate traffic volumes.

Signing Variables

The following major variables were included in the signing schemes tested.

1. Flags on Signs — It was initially decided to determine the influence on traffic flow of orange flags attached to the tops of signs. The results found here determined whether the flags would be used for the remaining tests. Mowing and shoulder operations signing conditions were used for the testing of flags vs. no flags.

2. Sign Colors — Two sign background colors, orange and yellow, were tested for mowing, shoulder and right lane closure signing conditions. The sign message was in black lettering in all cases.

3. Devices for Lane Closure Taper — Devices used for lane closing tapers were (a) high level warning devices (HLWD), (b) jumbo yellow cones, and (c) jumbo orange cones. In addition to these devices, octopus devices were used in delineating the work area for both mowing and shoulder operations.

4. Number of Indications — Signs were erected either on one or both sides of the southbound lane facing traffic for the three types of maintenance activities considered.

5. Position of "LANE CLOSED" Trailer — A trailer bearing the message "LANE CLOSED" and an arrow indicating the direction in which traffic should maneuver was placed at one of two positions; either at the beginning of the taper, or at the end.

6. Position of Electronic Sign Panel — An electronic sign panel approximately 6.5 feet wide, 3 feet high and standing 13.5 feet above the roadway was tested as a substitute for the "LANE CLOSED" trailer. This electronic panel had a sequentially moving arrow illuminated by high intensity lamps which could be seen from a distance in excess of 1 mile. This panel was also tested at two positions, at the beginning of the taper and at the end, for right lane closure signing conditions.

7. Position of Speed Limit Signs — Different positions of speed reduction signs relative to the work area were tested for some signing conditions. Conditions that included no speed control signs were also tested.

8. Sign Messages — Different sign messages were considered for the first two signs in the signing series for right lane closures. In one sequence, which was used unless otherwise noted, "repairs ahead" was the first sign, and "right lane closed ahead" was placed second. Other series used "lane closed, road work ahead" and "keep left" as the initial two signs. The last condition involved "repairs ahead, lane closed" for the first sign and "right lane closed ahead" for the second.

9. Sign Spacing — Signs were regularly spaced at 800' intervals, however, this interval was extended to 1000 - 1500' under various signing conditions.

10. Total Signing Schemes — Entire signing conditions incorporating the different variables mentioned above were analyzed in an attempt to arrive at a signing condition which would induce the safest traffic flow prior to and throughout the test work area.

A summary of the signing conditions tested for each type of maintenance operation is shown in Tables 1 through 4. Descriptive data for typical signs used in the schemes are given in Appendix A with drawings of the devices used.

Parameters Observed

To aid in the analysis of each scheme, the test site was divided into five zones as shown in Figure 1. For each zone, there were certain observed parameters which provided data needed to formulate a basis for comparing the different signing schemes. The parameters observed were as follows:

1. Weaving Maneuvers — An indication of the traffic flow characteristics throughout the test area was obtained by recording manually all weaving maneuvers for each of the five zones. For example, a vehicle weaving from lane 3 to lane 2 in Zone 1 as shown in Figure 1, would be classified as a 3 - 2 weave in Zone 1. By noting each time a vehicle weaves from one lane to another and in which zone the weave takes place, the magnitude and position of weaving maneuvers may be obtained.

2. Vehicle Speeds — An indication of the relative change in speeds within the work site was obtained by running spot speed radar checks at three points: at the beginning of Zone 1, at the beginning of Zone III, and at the work site within Zone V. Speeds were recorded for each lane.

TABLE 1

CONDITIONS TESTED FOR SHOULDER OPERATIONS

Indications[1]		Signs[2]							Devices[3]				Sign Color[4]		Flags[5]	Comments
Double	Single	Repairs Ahead	Reduce Speed Ahead	Speed Limit 45	Men Working	End Repairs	Shoulder Work Ahead	End Shoulder Work	Yellow Cones	Orange Cones	Octopus	HLWD	Yellow	Orange		
X		X	X	X	X	X							X		X	
X		X	X	X	X	X							X			
	X	X	X	X	X	X							X		X	
	X	X	X	X	X	X							X			
	X	X			X	X							X		X	
	X	X			X	X							X			
	X						X	X				X	X			
	X						X	X				X	X			
	X						X	X	X				X			
	X						X	X			X		X			
	X						X	X					X			
	X						X	X		X			X			
	X						X	X					X			
	X		X	X			X	X						X	X	
	X		X	X			X	X				X		X	X	
X		X	X	X	X	X								X	X	Repairs Ahead 3rd Sign Same
	X	X	X	X	X	X								X	X	

1/ Indications refer to signs either on one side or both sides of southbound traffic.
2/ All signs were 800' apart unless otherwise noted.
3/ Devices were positioned along maintenance area on paved shoulder.
4/ Sign color refers to background color for construction signs.
5/ Flags attached to top of each sign.

TABLE 2

CONDITIONS TESTED FOR MOWING OPERATIONS

Indications		Signs						Devices		Sign Color		Comments
Single	Double	Reduce Speed Ahead	Speed Limit 45	Mowing Operations Ahead	Men Working	End Repairs	End Mowing Operations	Octopus	HLWD	Orange	Yellow	
X		X	X	X		X					X	
X		X	X	X		X					X	
X		X	X	X		X					X	"Mowing Operations Ahead" First Sign
X				X		X					X	
X		X	X	X			X			X		
X				X			X			X		
X		X	X	X	X		X			X		"Mowing Operations Ahead" First Sign
X		X	X	X			X			X		"Mowing Operations Ahead" First Sign
X				X			X		X		X	High level warning devices along shoulder
X				X			X	X			X	Octopus devices along shoulder

TABLE 3

CONDITIONS TESTED FOR RIGHT LANE CLOSURE
(1968 - 1969)

Indications		Signs											Sign Color		Trailer Position[1]		Devices[2]		
Double	Single	Repairs Ahead	Road Work Ahead Lane Closed	Right Lane Closed Ahead	Repairs Ahead Lane Closed	Keep Left	Reduce Speed Ahead	Speed Limit 45	Lane Closed	End Repairs	Maximum Safe Speed 45	Maximum Safe Speed 55	Orange	Yellow	Close	Apart	Yellow Cones	Orange Cones	HLWD
	X*	X		X			X	X	X	X				X		X			X
X*		X		X			X	X	X	X				X	X				X
	X*	X		X			X	X	X	X				X	X				X
	X*	X		X			X	X	X	X				X		X	X		
	X*	X		X			X	X	X	X				X	X		X		
X*			X			X	X	X	X	X				X	X		X		
	X*		X			X	X	X	X	X				X	X		X		
	X*	X		X			X	X	X	X			X			X		X	
X*		X		X			X	X	X	X			X			X		X	
	X*	X		X			X	X	X	X			X			X		X	X
X+		X		X			X	X	X	X				X		X		X	
	X+	X		X			X	X	X	X				X		X		X	
	X+	X		X			X	X	X	X			X		X		X		
	X+	X		X			X	X	X	X			X		X			X	
	X+	X		X			X	X	X	X			X			X		X	
	X+	X		X			X	X	X	X			X			X	X		
	X+			X	X		X	X	X	X			X			X		X	
	X+				X	X	X	X	X	X			X			X		X	
	X+				X	X	X	X	X	X				X		X	X		
	X+				X	X	X	X	X	X				X		X		X	
	X+	X		X			X	X	X	X			X		X			X	
	X+	X		X			X	X	X	X			X		X			X	
	X+	X		X			X	X	X	X			X			X		X	
X+		X		X					X	X	X		X			X		X	
X+		X		X					X	X		X	X			X		X	
X+		X		X			X	X	X	X			X			X		X	X
X+		X		X					X	X			X			X		X	X
	X+	X		X			X	X		X				X	X			X	

1/ Position of lane closed trailer or sign panel (when noted) with reference to taper.
2/ Devices used for lane closure taper.

*1968

+1969

TABLE 4

CONDITIONS FOR RIGHT LANE CLOSURE
(1970)

Indications		Signs						Sign Color		Electronic Panel Position		Devices			
Double	Single	Repairs Ahead	Right Lane Closed Ahead	Reduce Speed Ahead	Speed Limit 45	Lane Closed	End Repairs	Yellow	Orange	Closed	Apart	Yellow Cone	Orange Cone	HLWD	Comments
X		X	X	X	X		X		X	X			X		
X		X	X	X	X		X		X		X		X		
	X	X	X	X	X		X		X		X		X		
	X	X	X	X	X		X	X			X	X			
	X	X	X	X	X		X		X	X			X		
X		X	X	X	X	X	X	X		X *		X			
X		X		X	X		X	X		X		X			Speed Limit - Second Sign
X		X	X	X	X		X		X	X			X		Speed Limit - Second Sign
X		X	X	X	X		X		X	X			X		Sign Spacing Increased
X		X	X	X	X		X		X		X		X		Sign Spacing Increased
X		X	X	X	X		X		X		X		X	X	4 HLWD - Work Area
X		X	X	X	X		X		X	X			X	X	4 HLWD - Work Area

* Sign trailer used in place of panel.

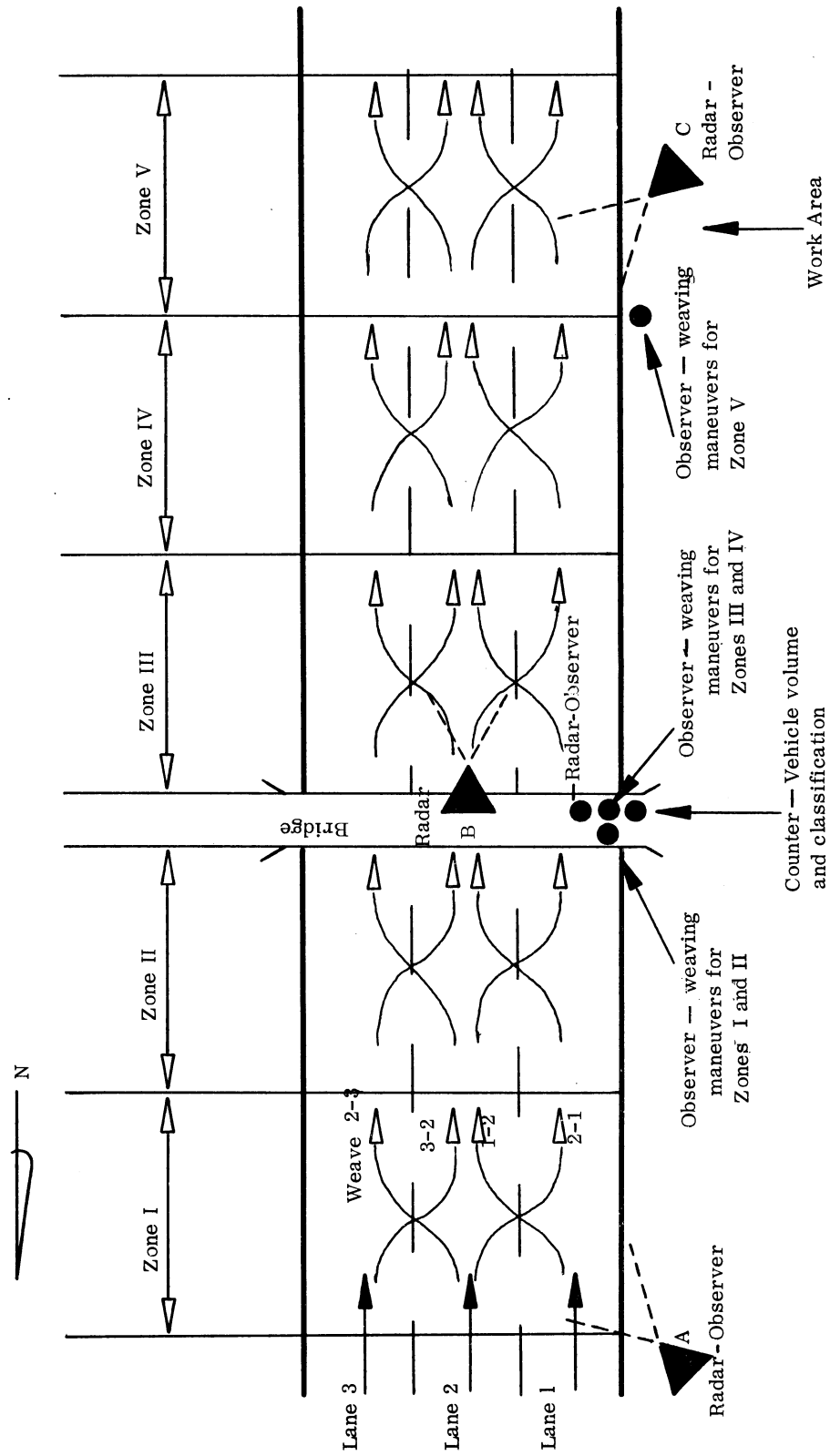

Figure 1. Schematic of test site showing observer positions and type of weaving maneuver.

3. Lane Volumes — All vehicles traversing the test area were counted and classified for each lane.

Testing was restricted to either Monday, Tuesday or Wednesday during the summer months of 1968, 1969 and 1970. Periodic tests were made without any devices or signs on the highway to get an indication of speeds and maneuvers for free flow traffic conditions. All data were taken by observers who were concealed as much as possible so as not to influence the flow of traffic in any manner. Weaving maneuvers, speeds, and volumes were recorded for each 15-minute interval during the 3 - 4 hour period in the morning or afternoon that was allotted for testing each scheme.

Discussion of Weaving and Speed Parameters

Magnitude of Weaving

The magnitude of weaving was determined for each signing scheme and was obtained by totaling all weaves throughout the test site and arriving at a percentage of weaves based on the traffic volume. This percent of weaves was compared with that found for other schemes thus providing a criterion for comparing different signing conditions based on the total number of weaves.

Position of Weaving

Any traffic control device should meet five elementary requirements *

(1) It should be capable of fulfilling an important need.

(2) It should command attention.

(3) It should convey a clear, simple meaning.

(4) It should command the respect of road users.

(5) It should be located to give adequate time for response.

The analysis of weaving positions was very important, especially for right lane closures, since this gives the degree of fulfillment of most of the requirements listed above.

* Manual on Uniform Traffic Control Devices for Streets and Highways, U. S. Department of Commerce, June 1961

In an attempt to identify weave position relative to the work area, zonal weaves were weighted, the amount depending on the distance from the zone to the work area. If vehicles can be induced to maneuver into the proper lane in an orderly manner before reaching the work area, the motorist should be able to negotiate the area with less confusion and, thus, greater safety. Therefore, the weaves within Zone V were weighted by a factor of five, in Zone IV by four, etc. The specific types of weaves considered were as follows:

(1) Total Weighted 1 - 2 Weaves — For right lane closures, the lane 1 to lane 2 weave is the only forced weave; therefore it is desirable to encourage this type of maneuver far enough in advance of the work area so that the motorist is not forced to weave by the lane closed taper. Since early 1 - 2 weaving allows an orderly maneuver and promotes safe passage through the work area, the position of this type of maneuver in relationship to the work area is a good indication of the adequacy of a signing scheme.

The total weighted lane 1 to lane 2 weave was obtained by weighting Zone III weaves by a factor of three, those in Zone II by two and Zone I by one.

(2) 1 - 2 Weaves in Zone III — This is the most important maneuver for right lane closures because it is a taper - forced maneuver which has to take place if the vehicle is not to enter the work area. By observing the weaving out of lane 1 in Zone III, a good indication of the relative hazard and adequacy of signing is obtained for each scheme.

(3) Total Weighted 2 - 1 Weaves + 2 - 3 Weaves + 2 - 3 Weaves for All Zones— In traversing the work area for right lane closures, vehicles in lane 2 and lane 3 are not forced to weave as only lane 1 is closed. Therefore by weighting all weaves (Zone 1 - Zone V), with the exception of lane 1 to lane 2 weaves, an indication of the position of non-forced weaves was obtained.

Open Roadway Weaving

Periodic checks were made in zonal weaving to provide data on the magnitude and position of weaving that could be expected with no signs or devices on the highway. This could be considered free flow weaving.

All weaving was taken as a percentage of the traffic volumes to compensate for variations in volume.

Speeds

It is not believed that speeds are as important as weaving maneuvers in the analysis of signing schemes. In various schemes a speed limit of 45 miles per hour was posted, which means that under ideal conditions traffic would flow through the work area at this speed. However, as is well known, the majority of the vehicles travel at a somewhat higher speed, and slow for the activity — not the speed limit sign.

Speed checks were also made with no signs or devices on the highway to gain a measure of the free flow speeds through the test area.

A schematic of the test area was shown in Figure 1, which gave radar and weaving maneuver observation positions. It should be noted that radar position A was used for speed data taken in 1969 and 1970, however, for 1968 point A was 2400 feet in advance of Zone 1.

RESULTS

The results are based on the analysis of vehicle weaving maneuvers and speeds, and the general opinion of the author from his observation of the tests. The analysis of weaving maneuvers consisted of determing the magnitudes and position of weaves within the test site for each signing condition tested.

Open Roadway

For all open roadway data it was found that the mean total percent weaves was 16.0% and that the means for the zones ranged from 2.7% to 3.7%, as shown in Table 5. The means and standard deviations for speeds at observation points A, B and C, (shown earlir in Figure 1) are shown in Table 6, where it can be seen that the mean decrease in speed between point B and point C (the work area) was 5.0 mph.

TABLE 5

PERCENT OPEN ROADWAY WEAVES

Zone	I	II	III	IV	V	All Zones
Mean	3.1	3.7	3.2	2.7	3.3	16.0

TABLE 6

OPEN ROADWAY SPEEDS IN MILES PER HOUR

Observation Position	A	B	C
Mean Speed	62.4	65.0	60.0
Standard Deviation	1.67		

The variations in speeds between the observation points could be a result of the minor grade variation within the test site. The entire test site is on a slight downgrade, however, the grade is not consistent.

Since the roadway is built to interstate standards, other geometric conditions would most likely not significantly affect the open roadway speeds. However, there is an off-ramp approximately 1/2 mile beyond Point C.

Variables

Flags on Signs

Initially, it was decided to determine whether the attachment of flags to the signs would aid in controlling traffic at the test site. Therefore, several shoulder and mowing operations sign schemes were tested with and without flags to determine their effects.

As can be seen from the total, total weighted and 1 - 2 weaves shown in Table 7, two out of the four comparisons (2 and 3) show the conditions with flags to have a higher percent of weaves. The remaining conditions (1 and 4) show very little difference in weaving.

TABLE 7

SUMMARY OF WEAVES AND SPEED DATA FOR FLAGS VERSUS NO FLAGS ON SIGNS

Signing Conditions	Percent Weaves			Mean Speeds			Variables
	Total	Total Weighted	1 - 2	A	B	C	
Shoulder Operations Double indications Yellow Signs (1) Speed Limit	25.9	78.8	13.9	61.8	64.6	55.9	flags
	24.7	76.0	12.6	62.1	65.3	55.7	no flags
Shoulder Operations Single Indications Yellow Signs (2) Speed Limit	30.4	94.4	15.1	58.1	64.2	55.7	flags
	26.7	86.9	14.0	59.3	64.2	53.9	no flags
Shoulder Operations Single Indications Yellow Signs (3) No Speed Limit	26.9	86.4	14.9	62.4	67.2	58.8	flags
	20.2	61.6	11.2	61.6	66.7	57.9	no flags
Mowing Operations Single Indications Yellow Signs (4) Speed Limit	19.0	57.2	7.6	62.1	63.4	60.2	flags
	19.4	57.7	8.4	61.8	63.9	60.0	no flags

Indications are that flags on the signs may tend to increase weaving; however, the increase is minimal.

Based on the open road speed variability shown in Table 7, there does not seem to be any significant difference in speeds for schemes with and without flags, as the differences are in the 0 - 2 mph range. In addition, from observation of the signs with and without flags, the flags have an advantage in attention getting because of their color and movement. Therefore, it was decided to include flags in all the schemes tested.

Sign Color

At the time these tests were initiated, an orange color was being considered for temporary warning signs. Therefore, it was decided to test signs with an orange background in addition to those with the normal yellow background in an attempt to evaluate the effectiveness of the former.

Comparing total, total weighted, and 1 - 2 weaves as shown in Table 8 for mowing operations, there is very little difference in the three conditions investigated. When analyzing weaving for mowing and shoulder operations, only the total, total weighted and 1 - 2 weaves were considered because these types of operations did not involve forced lane 1 to lane 2 weaves, as did the right lane closures. For right lane closures, yellow signs resulted in fewer total weaves under three conditions (4, 8 and 9); the orange signs induced fewer weaves under two conditions (5 and 6); and under one condition (7), there was no apparent difference between the colors. Total weighted weaves were fewer in two cases (5 and 6) for the orange; in two cases (4 and 9) for the yellow; in two cases (7 and 8), there were no differences. For 1 - 2 and 1 - 2 weighted weaves, yellow was better under three conditions (4, 8 and 9), while orange was better under one (6), and under two (5 and 7) there were no differences. Of the six conditions (4 - 9) compared there was very little difference in the 2-1, 2-3, 3-2 weighted weaves for sign colors.

In summary, the analysis of weaves for the sign color variable showed few differences, however, the yellow background seemed to have an edge with slightly more conditions showing fewer weaves. It should be noted that the only condition tested for the double sign indication showed orange signs to have fewer weaves for three of the five conditions considered. Also, the variable of sign color was not tested in conjunction with the electronic sign panel.

TABLE 8

SUMMARY OF WEAVES FOR THE ORANGE AND THE YELLOW SIGNS

Signing Conditions	Percent Weaves						Variable
	Total	Total Weighted	1 - 2	1 - 2 Weighted	2-1, 2-3, 3-2 wtd.	1 - 2in Zone III	
Mowing Operations Single Indications Speed Limit Flags * (1)	18.7	52.9	8.0				Yellow Signs
	20.5	59.7	7.3				Orange Signs
Mowing Operations Single Indications No Speed Limit Flags (2)	17.2	48.4	8.7				Yellow Signs
	16.8	49.3	7.4				Orange Signs
Mowing Operations Single Indications Speed Limit Flags ** (3)	19.0	57.2	7.6				Yellow Signs
	18.1	54.4	7.8				Orange Signs
Right Lane Closure Single Indications Orange Cones Trailer Apart (4)	37.2	80.2	18.0	26.9	53.4	2.2	Yellow Signs
	40.9	86.3	19.9	31.5	54.8	2.6	Orange Signs
Right Lane Closure Double Indications Orange Cones Trailer Apart (5)	43.1	96.3	22.9	36.7	58.8	3.4	Yellow Signs
	37.3	77.6	21.1	36.1	41.2	3.6	Orange Signs
Right Lane Closure Single Indications Yellow Cones Trailer Apart (6)	52.7	108.8	33.1	58.3	50.5	8.0	Yellow Signs
	41.1	92.9	22.7	41.7	51.2	6.0	Orange Signs
Right Lane Closure Single Indications Orange Cones Trailer Apart (7)	23.6	58.4	6.4	10.9	47.6	1.2	Yellow Signs
	23.9	60.3	6.2	10.0	50.3	1.3	Orange Signs
Right Lane Closure Single Indication Orange Cones Trailer Close (8)	31.6	68.8	14.5	20.3	42.5	2.7	Yellow Signs
	36.5	69.1	18.9	28.7	40.4	3.7	Orange Signs
Right Lane Closure Single Indications Orange Cones (9) Sign Panel Close	38.8	81.0	14.3	26.4	54.7	1.6	Yellow Signs
	46.9	99.8	23.7	40.2	59.5	2.2	Orange Signs

* 5 Signs: Mowing Operations Ahead; Reduce Speed Ahead; Speed Limit 45; Men Working; End Mowing Operations.

**4 Signs: Reduce Speed Ahead; Speed Limit 45; Mowing Operations Ahead; Mowing Operations.

Table 9 gives the mean speeds at observation points A, B and C for both the yellow and orange signs under the schemes tested. For conditions 1 and 2 orange signs have lower mean speeds at B than do the yellow signs; however, this is not reflected at C, where the speeds are similar. For condition 3, there was little difference in the speeds at point B, while at C there were lower speeds for the yellow signs. It is noted that under the two conditions (1 and 2) for which orange signs had lower speeds, speed limit signs were included in the scheme, whereas under the other condition there were no speed limit signs.

The mean speeds for right lane closures shown in Table 9 give no logical basis for judging whether the yellow or the orange signs were more effective in altering speeds. Under some conditions yellow signs appeared more effective, whereas under others orange signs showed lower speeds. Under many schemes, there were no speed differences between the signs.

From observations in runs through the work site, the orange signs seemed to have better attention getting qualities; however, there is some question about the legibility of the black messages on an orange background.

Devices

Different types of devices were placed along the shoulder within the work area to test their influence on traffic flow. As seen from Table 10 orange cones caused more total, weighted total, and 1 - 2 weaves, and high level warning devices caused the next highest number. The signing schemes with either no devices or octopus devices caused the fewest weaves in all cases. The small octopus devices were extremely difficult to see and therefore had very little influence on traffic flow, as noted.

TABLE 9

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SUMMARY OF SPEED DATA FOR THE ORANGE AND THE YELLOW SIGNS

Sign Conditions	Mean Speeds			Variables
	A	B	C	
Mowing Operations Single Indications Speed Limit (1) Flags	61.0	64.7	61.4	Yellow Signs
	61.5	59.8	61.4	Orange Signs
Mowing Operations Single Indications(2) Speed Limit 1st Sign Flags	62.1	63.4	60.2	Yellow Signs
	63.8	60.9	60.4	Orange Signs
Mowing Operations Single Indications No Speed Limit (3) Flags	60.6	65.0	61.4	Yellow Signs
	62.1	64.2	63.5	Orange Signs
Right Lane Closure Single Indications Orange Cones (4) Trailer Apart	**59.9	58.6	56.8	Yellow Signs
	**61.1	58.4	55.7	Orange Signs
Right Lane Closure Double Indications Orange Cones (5) Trailer Apart	**59.3	57.2	54.9	Yellow Signs
	**60.9	56.5	51.6	Orange Signs
Right Lane Closure Single Indications Yellow Cones (6) Trailer Apart	**62.5	60.4	58.7	Yellow Signs
	**60.0	58.2	56.9	Orange Signs
Right Lane Closure Single Indications Orange Cones (7) Trailer Apart	56.3	55.0	57.1	*** Yellow Signs
	**58.8	57.6	57.1	*** Orange Signs
Right Lane Closure Single Indications Orange Cones (8) Trailer Close	62.9	60.5	56.2	**** Yellow Signs
	63.2	60.8	55.9	**** Orange Signs
Right Lane Closure Single Indications Orange Cones Electronic Sign (9) Panel	61.3	59.3	54.7	Yellow Signs
	60.9	62.4	55.1	Orange Signs

* 68 Speed Data
** 68 & Other Years
*** First 2 Signs "Lane Closed, Repairs Ahead" and "Keep Left"
**** Signs Extended (1000' - 1500')

TABLE 10

SUMMARY OF WEAVE AND SPEED DATA FOR DEVICES
USED IN SHOULDER AND MOWING OPERATIONS

Signing Conditions *	Percent Weaves			Mean Speeds			Variables
	Total	Total Weighted	1 - 2	A	B	C	
Shoulder Operations	32.1	10.4	15.9	62.1	66.1	64.0	Orange Cones
Yellow Signs	24.9	71.9	13.8	62.4	65.4	63.4	None
Single Indications	26.7	87.3	14.8	62.3	68.6	66.6	Yellow Cones
No Speed Limit	23.5	74.8	13.1	62.8	67.6	65.2	Octopus
No Flags	31.2	96.8	19.3	61.3	66.1	57.4	High Level Device
Mowing Operations	16.8	47.3	7.5	63.5	63.9	61.6	High Level Device
Single Indications	13.8	39.9	6.1	62.3	62.5	59.8	Octopus
Orange Signs							
Flags							
No Speed Limit							

* All conditions reflect 1968 data

The speed comparisons shown in Table 10 indicate that for shoulder operations the high level warning device seems to slow the traffic more at the work area (point C) than do the other devices. The two observations for mowing operations show little difference in speeds at all points for the high level and octopus warning devices.

A summary of the different types of weaves considered for devices used in conjunction with right lane closure signing schemes is shown in Table 11.

Under the majority of the right lane closure signing conditions considered orange cones induced the lowest percentage of weaving within the test site. Based on the total magnitude of weaving, orange cones had fewer weaves in six out of the seven signing conditions, while in the other the combination of orange cones and high level warning devices appeared to be superior. An analysis of the weaving position within the test site indicated that orange cones persuaded earlier maneuvering into the proper lanes, and thereby helped to eliminate the hazardous forced weave out of lane 1 just prior to the closed lane taper and work site.

Comparatively, yellow cones had the highest total weaves and had a less than desirable effectiveness in dissuading weaves close to the work area. This is exemplified in Figure 2, which shows a plot of the percent 1 - 2 weaves for Zones I, II and III. Yellow cones, as compared with orange cones, had higher weaves for each zone, especially Zone III, the farthest point in the open portion of lane 1. In observations of the devices from the motorists' view in negotiating the test area, orange cones gave a good delineation of the taper, whereas yellow cones caused confusion. It is felt that this good delineation results from the color contrast of the orange cones in relation to the pavement and background.

High level warning devices had good attention getting characteristics because of the flags, color, and motion; however, these devices gave a poor indication of the taper line as a result of the bottom flags being only 2 - 3 feet above the pavement surface.

A comparison of the speeds for all signing schemes incorporating the devices considered is shown in Table 12. Referring to the speeds at point C, it is noted that consistently lower speeds are shown for orange cones; however, the significance of this result is questionable because of the variability noted in the open roadway schemes.

TABLE 11

SUMMARY OF WEAVING FOR RIGHT LANE CLOSURE
USING VARIOUS TAPER DEVICES

gning nditions	Percent Weaves						Variables
	Total	Total Weighted	1 - 2	1 - 2 Weighted	2-1 + 2-3+ 3-2 wtd.	1 - 2 Weaves Zone III	
uble Indications	51.9	129.4	31.1	68.4	63.0	9.7	Yellow Cones
llow Signs	38.9	100.9	23.5	51.2	49.5	6.2	Orange Cones
ailer Close (1)	52.7	116.7	34.4	64.6	52.1	6.9	HLWD
ngle Indications	37.2	80.7	17.9	26.9	53.4	2.2	Orange Cones
llow Signs	52.7	108.8	33.1	58.3	50.5	8.0	Yellow Cones
ailer Apart(2)	35.7	80.9	17.1	28.5	52.3	2.5	HLWD
ngle Indications	38.7	78.2	20.5	32.4	45.7	2.6	HLWD
llow Signs ailer Apart (3)	43.2	95.0	23.8	44.1	50.0	5.9	Yellow Cones
ngle Indications	40.8	86.3	19.9	31.5	54.8	2.6	Orange Cones
ange Signs	41.1	92.9	22.8	41.7	51.2	6.0	Yellow Cones
ailer Apart(4)	24.5	54.8	11.6	19.6	35.2	1.6	Orange Cones & HLWD
ngle Indications	44.9	95.3	29.8	53.5	41.7	6.5	Yellow Cones
ange Signs ailer Close(5)	38.4	81.0	22.1	36.6	44.5	3.4	Orange Cones
ngle Indications	33.1	82.0	12.3	22.6	59.3	3.2	Yellow Cones
llow Signs ailer Apart(6)	23.6	58.4	6.4	10.9	47.6	1.2	Orange Cones
uble Indications	37.3	77.6	21.1	36.1	41.2	3.6	Orange Cones
range Signs ailer Apart(7)	42.0	100.8	21.2	40.3	66.5	2.9	Orange Cones & HLWD
ngle Indications	44.8	94.4	27.0	45.7	48.6	5.0	HLWD
llow Signs	45.1	108.9	26.4	54.5	54.4	9.7	Yellow Cones
ailer Close (8)	32.3	72.4	17.9	35.0	37.4	4.9	Orange Cones

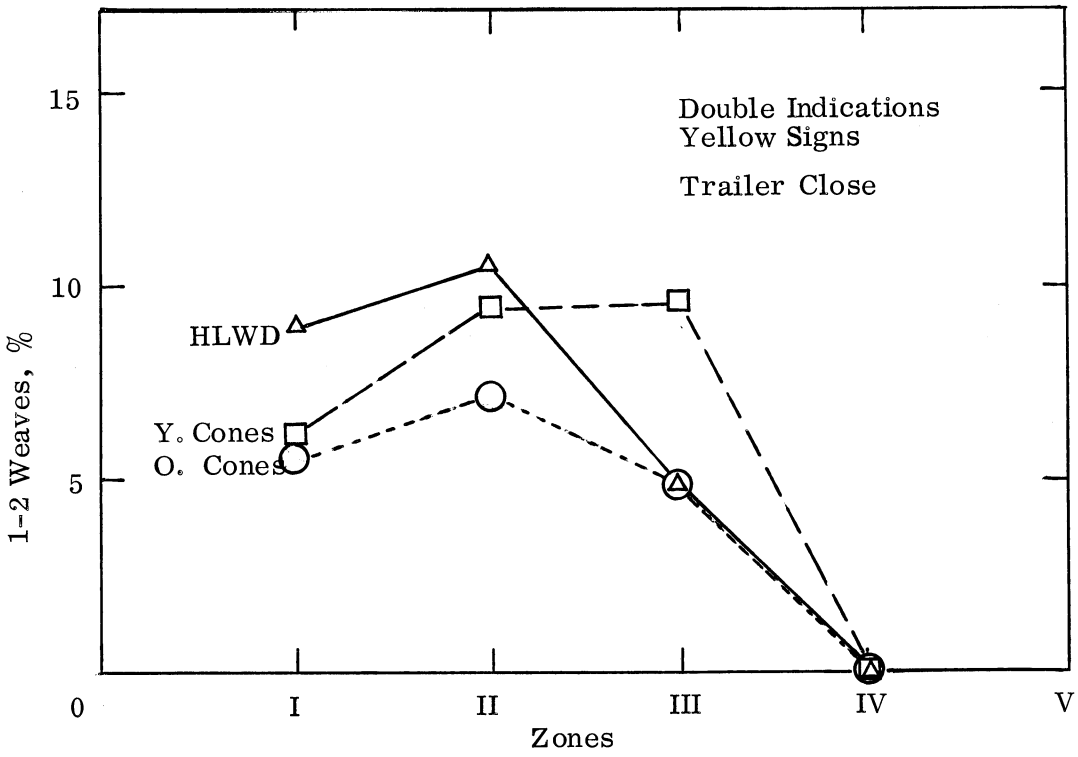

Figure 2. Zonal (1-2) weaves for devices — right lane closed.

Number of Indications

Tests were conducted with signs on one and both sides of the highway, however, it is felt that for any kind of maintenance activity on limited access highways signs should be erected on both sides. With the increasing traffic volumes, higher speeds and truck percentages, driver fatigue, etc., it becomes increasingly likely for signs only on one side to be partially blocked out or ignored, thereby lending to the hazardous situation wherein motorists traverse the maintenance work area without consciousness of the activity.

Signs erected on one side, however, did aid in the analysis of the variables considered, in addition to giving a comparison of driver reactions for signs on one and both sides of the highway.

TABLE 12

SUMMARY OF SPEEDS FOR DEVICES
RIGHT LANE CLOSURE

ign Conditions	Mean Speeds			Variables
	A	B	C	
ouble Indications	*63.4	58.0	54.0	Yellow Cones
ellow Signs	*63.4	58.1	50.8	Orange Cones
railer Close (1)	*61.3	57.3	54.4	High Level Device
ngle Indications	*62.5	60.4	58.7	Yellow Cones
ellow Signs (2)	*62.0	58.6	56.7	Orange Cones
railer Apart	*61.6	57.7	57.2	High Level Device
ngle Indications	*61.9	60.6	60.4	Yellow Cones
ellow Signs (3) railer Apart	*62.7	59.5	59.6	High Level Device
ngle Indications	*61.2	58.2	56.9	Yellow Cones
range Signs (4)	*62.8	58.4	55.7	Orange Cones
railer Apart	61.6	59.8	54.6	Orange Cones & High Level Device
ngle Indications	59.4	59.0	57.0	Yellow Cones
range Signs (5) railer Close	59.1	59.6	57.1	Orange Cones
ngle Indications				
ellow Signs (6)	56.8	56.3	59.0	Yellow Cones
railer Apart	56.3	55.0	57.1	Orange Cones
ouble Indications				Orange Cones
range Signs (7)	57.4	57.7	53.3	& High Level Device
railer Apart	*60.9	56.5	51.6	Orange Cones
ngle Indications	*63.5	63.0	55.6	Yellow Cones
ellow Signs (8)	*62.8	61.5	54.6	Orange Cones
railer Close	62.0	58.9	55.4	High Level Device

1968 Speeds

Referring to Table 13, the total, total weighted, and 1 - 2 weaves were slightly lower for double indications used for shoulder operations, whereas speeds were inconsistent for each variable, with no appreciable differences in the averages for each variable at points A, B and C.

TABLE 13

SUMMARY OF SPEED AND WEAVE DATA FOR NUMBER OF INDICATIONS SHOULDER OPERATIONS

ign Conditions	Total Weaves (%)	Total Weighted Weaves (%)	1-2 Weaves (%)	Mean Speeds A	B	C	Variable
houlder Operations	26.0	79.8	14.0	61.8	64.6	55.9	Double Ind.
'ellow Signs (1)	30.4	94.4	15.1	58.1	64.2	55.7	Single Ind.
'lags							
peed Limit							
houlder Operations	24.7	76.0	12.6	62.1	65.3	55.7	Double Ind.
'ellow Signs	26.7	86.9	14.0	59.3	64.2	53.9	Single Ind.
Io Flags (2)							
peed Limit							
houlder Operations	19.9	60.9	8.9	61.7	60.5	58.3	Double Ind.
)range Signs	23.3	70.5	10.8	61.6	62.8	58.5	Single Ind.
'lags (3)							
peed Limit							

From the different types of weaves for right lane closures shown in Table 14, it is obvious that under the majority of the conditions, single indications produce fewer weaves than do double indications. However, keeping in mind the statements made concerning the desirability of double indications in lieu of single indications, it is interesting to note that for the total, total weighted, 1 - 2, 1 - 2 weighted, and 1 - 2 in Zone III weaves, double indications compare favorably with those observed for single indications under condition 1 (orange signs, orange cones, electronic sign panel apart). This is especially noted for the relatively few weaves out of lane 1 in Zone III, which signify a safe condition. Also it is interesting to note that condition 1 incorporated the electronic sequential arrow in conjunction with the signs. Among the conditions producing relatively high 1 - 2 weaves close to the work area were

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TABLE 14

SUMMARY OF WEAVES FOR NUMBER OF INDICATIONS
RIGHT LANE CLOSURE

ning nditions	Total	Total Weighted	Percent Weaves 1 - 2	1 - 2 Weighted	2-1 + 2-3 + 3-2 Wtd.	1 - 2 Weaves Zone III	Variables
ange Signs	40.6	82.6	19.6	28.4	55.1	1.5	Double
ange Cones rly Warner art (1)	35.6	69.1	15.2	20.8	47.8	0.9	Single
ange Signs	46.3	92.6	23.1	36.4	58.9	1.4	Double
ange Cones rly Warner se (2)	49.7	99.8	25.6	40.4	59.5	2.2	Single
llow Signs	51.4	101.0	27.3	42.6	58.4	4.0	Double *
llow Cones ailer se (3)	37.8	72.2	20.1	29.1	43.1	2.4	Single *
llow Signs WD	52.7	116.7	34.4	64.6	52.1	6.9	Double
ailer se (4)	44.8	94.4	27.0	45.7	48.6	5.0	Single
ange Signs	37.3	77.6	21.1	36.1	41.2	3.6	Double
ange Cones ailer art (5)	39.6	83.6	19.1	31.1	52.6	2.2	Single
llow Signs	43.1	96.3	22.9	36.7	53.8	3.4	Double
ange Cones ailer art (6)	37.2	80.2	18.0	26.9	52.4	2.2	Single
llow Signs	38.9	100.9	23.5	51.2	49.5	6.2	Double
ange Cones ailer se (7)	45.1	108.9	26.4	54.4	54.4	9.7	Single
llow Signs	47.1	125.3	28.5	62.3	63.0	8.5	Double
llow Cones ailer ose (8)	32.3	72.4	17.9	35.0	37.4	4.9	Single

First two signs different 1)"LANE CLOSED ROAD WORK AHEAD" 2) Keep left

condition 4 (yellow signs, high level warning devices, and trailer apart); condition 7 (yellow signs, orange cones, and trailer close); and condition 8 (yellow signs, yellow cones and trailer close).

Referring to Table 15, it is noted that speeds for the double and single indications at point A are similar in most instances; however, the speeds for points B and C reveal a definite slowdown for double indications as opposed to single.

TABLE 15

MEAN SPEED FOR SINGLE AND DOUBLE INDICATIONS — RIGHT LANE CLOSURE

Sign Conditions	Mean Speeds			Variable
	A	B	C	
Orange Signs Orange Cones Early Warner Apart (1)	56.9	58.2	53.7	Double
	60.7	59.0	56.0	Single
Orange Signs Orange Cones Early Warner Close (2)	61.0	57.4	52.2	Double
	60.9	62.2	55.1	Single
Yellow Signs Yellow Cones First 2 Signs Diff. (3)	*61.5	58.4	52.5	Double **
	*62.2	61.1	55.2	Single **
Yellow Signs HLWD Trailer Apart (4)	*61.3	57.3	54.4	Double
	*62.0	58.9	55.4	Single
Orange Signs Orange Cones Trailer Apart (5)	*60.9	56.5	51.6	Double
	*62.8	59.4	53.4	Single
Yellow Signs Orange Cones Trailer Apart (6)	*62.7	57.0	54.2	Double
	*62.0	58.5	56.5	Single
Yellow Signs Orange Cones Trailer Close (7)	*63.4	58.4	50.8	Double
	*63.5	63.0	55.7	Single
Yellow Signs Yellow Cones Trailer Close (8)	*63.4	58.8	51.6	Double
	*62.8	61.5	54.6	Single

* 1968 Data

** First Sign: "Lane Closed and Road Work Ahead"
Second Sign: "Keep Left"

Position of Trailer

The trailer with the message "LANE CLOSED" was tested at two positions: at the start of the taper and at the end of the taper. The major difference between these schemes is that when the trailer was at the beginning of the taper each advance sign was moved back, away from the taper, 800 feet. It should be noted that under this variable the electronic sign panel, which is interchangeable with the trailer, was not considered.

The weaves induced by the two different trailer positions are shown in Table 16. For total and total weighted weaves, there is no apparent advantage for either trailer position. Also, it seems that the "trailer apart" position does a much better job in getting motorists out of the dangerous lane sooner, as noted by the lower number of 1 - 2 weighted and 1 - 2 Zone III weaves for six out of seven conditions (all except 3).

A study of the speeds in Table 17 reveals that neither trailer position appreciably influenced the speeds at points A, B or C. Under some conditions, the speeds for "apart" were slightly lower, whereas under others the reverse was true.

Position of Electronic Sign Panel

Midway through the project an electronic signing panel with a sequentially moving arrow was obtained for testing in conjunction with right lane closed maintenance operations. The sign panel has good target value and is highly visible at great distances, as evidenced by the distances at which drivers become aware of it.

To obtain further information on the sign panel, questionnaires were sent to the Departments' district traffic, maintenance, and construction engineers and each resident engineer to gain their thoughts on the use of the panel. The overwhelming opinion of the engineers was that it was extremely effective in lane closure, center line marking, redirection of traffic during cleanup of wrecks (night and day), and any night work on highways. The panel has a dimming mechanism for eliminating dangerous glare during night use.

All persons answering the questionnaires were in agreement that the cost of the panel is justified. The use of the sign panel can cut down on site oversigning, since it readily conveys its message to the motorists. The cost can be justified in the savings of wages for flagmen aside from the added safety it provides.

TABLE 16

SUMMARY OF WEAVES FOR TRAILER POSITION
RIGHT LANE CLOSURE

gning onditions	Percent Weaves						Variable
	Total	Total Weighted	1 - 2	1 - 2 Weighted	2-1, 2-3, 3-2 wtd.	1 - 2 in Zone III	
ouble Indications ellow Signs range Cones (1)	38.9	100.9	23.5	51.2	49.5	6.2	Close
	43.1	96.3	22.9	39.7	58.8	3.4	Apart
ngle Indications ellow Signs range Cones (2)	45.1	108.9	26.4	54.5	54.4	9.7	Close
	37.2	80.2	18.0	26.9	53.4	2.2	Apart
ngle Indications ellow Signs ellow Cones (3)	32.3	72.4	17.9	35.0	37.4	4.9	Close
	52.7	108.8	33.1	58.3	50.5	8.0	Apart
ngle Indications ellow Signs igh Level Warning Device (4)	44.8	94.4	27.0	45.7	48.6	5.0	Close
	35.7	80.9	17.1	28.5	52.3	2.5	Apart
ngle Indications range Signs ellow Cones (5)	44.9	95.3	29.8	53.5	41.7	6.5	Close
	41.1	92.9	22.7	41.7	51.2	5.7	Apart
ngle Indications range Signs range Cones (6)	38.4	81.0	22.1	36.6	44.5	3.4	Close
	40.9	86.3	19.9	31.5	54.8	2.6	Apart
ngle Indications range Signs range Cones igns Extended (7)	36.5	69.1	18.9	28.7	40.4	3.7	Close
	35.6	88.8	14.0	25.8	62.7	2.2	Apart

TABLE 17

SUMMARY OF SPEEDS FOR TRAILER POSITION
RIGHT LANE CLOSURE

Sign Conditions	Mean Speeds			Variable
	A	B	C	
Double Indications Yellow Signs Orange Cones	*63.4	58.5	50.8	Close
	**59.3	57.2	54.2	Apart
Single Indication Yellow Signs Orange Cones	**63.4	61.9	55.8	Close
	**59.9	58.6	56.8	Apart
Single Indication Yellow Signs Yellow Cones	*62.5	60.4	58.7	Close
	*62.8	61.5	54.6	Apart
Single Indication Yellow Signs HLWD	*62.0	58.9	55.4	Close
	*61.6	57.7	57.2	Apart
Single Indication Yellow Signs Orange Cones	59.4	59.0	57.0	Close
	**60.0	58.2	56.9	Apart
Single Indication Orange Signs Orange Cones	59.1	59.6	57.1	Close
	**61.3	58.9	55.4	Apart
Single Indication Orange Signs Orange Cones Signs Extended	63.2	60.8	55.9	Close
	59.5	61.9	57.2	Apart

* 1968 Data
** Combination of 1968, 1969, 1970

Engineers who had observed the panel in operation were impressed with it, and several whose districts did not possess a panel were planning to obtain one.

In the summer of 1970, tests were conducted with this sign in place of the "LANE CLOSED" trailer. Like the trailer, the sign panel was placed in conjunction with the sign at the taper start and also at the end.

There were four signing conditions in which the electronic panel and trailer were interchanged. As seen from Table 18 there were two conditions under which the trailer had fewer total and total weighted weaves and two under which the sign panel had fewer weaves. However, from a comparison of the weaves out of lane 1, especially those in Zone III, under the majority of the conditions the sign panel appeared to be superior.

As shown in Table 19, speeds at observation points B and C seem to be slightly lower for the trailer as opposed to the panel. No pattern of differences can be noted in speed differentials between points B and C for the four signing conditions.

TABLE 18

SUMMARY OF WEAVES FOR SIGN PANEL VS.
TRAILER - RIGHT LANE CLOSURE

Signing Conditions	Percent Weaves						Variable
	Total	Total Weighted	1 - 2	1 - 2 Weighted	2-1+2-3+ 3-2 wtd.	1 - 2 in Zone III	
Double Indications Orange Signs Orange Cones Apart	37.3	77.6	21.1	36.1	41.2	3.6	Trailer
	42.2	88.1	21.1	33.1	55.1	1.4	Early Warner
Single Indications Orange Signs Orange Cones Apart	39.6	83.6	19.1	31.1	52.6	2.2	Trailer
	31.8	67.5	12.6	19.7	47.8	0.9	Early Warner
Single Indications Orange Signs Orange Cones Close	38.4	81.0	22.1	36.6	44.5	3.4	Trailer
	46.9	99.8	24.1	40.2	59.5	2.2	Early Warner
Single Indications Yellow Signs Yellow Cones Apart	52.7	108.8	33.1	58.3	50.5	8.0	Trailer
	40.3	82.8	20.6	33.2	49.6	3.5	Early Warner

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TABLE 19

SPEED SUMMARY FOR TRAILER VS. SIGN PANEL
RIGHT LANE CLOSED

Sign Conditions	Mean Speeds A	B	C	Variable
Double Indications Orange Signs Orange Cones Apart	*60.9	56.5	51.6	Trailer
	57.5	58.0	53.8	Early Warner
Single Indication Orange Signs Orange Cones Apart	*62.8	59.4	53.4	Trailer
	60.7	59.0	56.0	Early Warner
Single Indication Orange Signs Orange Cones Close	59.4	59.0	57.0	Trailer
	60.9	62.2	55.1	Early Warner
Single Indication Yellow Signs Yellow Cones Apart	*62.5	60.4	58.7	Trailer
	59.1	61.3	58.3	Early Warner

* 1968 Data

Conditions 1-6, as shown in Table 20, show the relative positions of the electronic sign panel and signs. For conditions 1 and 2 the electronic sign panel was positioned at the beginning (apart) of the taper and at the end (close) with the signs being left in the same place for both conditions. It can be seen that under condition 1 fewer weaves occurred with the panel apart; however, condition 2 weaves indicate no clear advantage for either position of the panel (close or apart).

Both the sign panel and signs were moved for conditions 3 and 4, as was the case with the trailer. It is clear from the table that the sign panel apart has the lower percentage of weaves in most instances.

SUMMARY OF WEAVES FOR SIGN PANEL POSITION — RIGHT LANE CLOSURE

Signing Conditions	Percent Weaves						Variables
	Total	Total Weighted	1 - 2	1 - 2 Weighted	2-1 + 2-3 + 3 - 2 Wtd.	1 - 2 In Zone III	
Double Indications	40.1	93.7	16.5	30.7	63.0	4.1	Close
Orange Signs (1)	33.8	77.0	11.9	20.5	56.6	2.2	Apart
Orange Cones							
Double Indications	55.1	117.8	22.1	32.3	85.5	2.3	Close
Orange Signs (2)	50.0	110.1	22.0	34.7	75.4	3.3	Apart
Orange Cones							
Double Indications	42.2	88.1	21.1	33.1	55.1	1.4	Close
Orange Signs (3)	44.6	101.4	23.6	42.1	59.3	2.4	Apart
Orange Cones							
Single Indications	46.9	99.8	24.1	40.2	59.5	2.2	Close
Orange Signs (4)	31.8	67.5	12.6	19.7	47.8	0.9	Apart
Orange Cones							
Double Indications	40.6	82.6	19.6	28.4	55.1	1.5	Sign at 800'
Orange Signs (5)	33.8	77.0	11.9	20.5	56.6	2.2	Signs at 1000-1500'
Orange Cones							
Double Indications	48.3	101.4	26.1	43.4	59.3	2.4	Signs at 800'
Orange Signs (6)	48.6	108.4	23.7	44.7	63.8	4.5	Signs at 1000'-1500' *
Orange Cones	40.1	93.7	16.5	30.7	63.0	4.1	Signs at 1000' -1500'**

(1) Signs 1000' - 1500'; Sign Panel Moved
(2) High Level in Work Area; Panel Moved
(3) Sign Panel and Signs Moved
(4) Sign Panel and Signs Moved
(5) Sign Panel Stationary at End of Taper; Sign Spacing Varied
(6) Sign Panel Stationary at Beginning of Taper; Sign Spacing Varied

* Sign Sequence Changed; "Speed Limit 45" Before "Right Lane Closed Ahead"
** Regular Sign Sequence, "Right Lane Closed Ahead" Before" Speed Limit 45"

Under condition 5 the sign panel was at the end of the taper, the variable being the spacing between signs, which was either 800 feet or 1000-1500 feet. Under the extended sign spacing (1000-1500'), the fewest weaves were recorded with the exception of (2-1) + (2-3) + (3-2) weighted, where there was no appreciable difference, and (1-2) weaving in Zone III, where the regularly spaced signs (800') induced a slightly lower percentage of weaves.

Condition 6 was the same as condition 5; however, the electronic sign panel was positioned at the beginning of the taper. It should be noted that under one case where signs were placed at 1000-1500 feet in condition 6 the "right lane closed ahead" sign and the "speed limit 45" sign were interchanged. Extended signs (1000-1500') in the regular sign sequence exhibited fewer total, total weighted, 1 - 2 and 1 - 2 weighted weaves than in the other two, which showed no appreciable difference. Comparing the three schemes within condition 6 it is noted that the extended signs (1000-1500') in the regular sign sequence induced fewer total, total weighted, 1 - 2, and 1 - 2 weighted weaves than did the remaining two. There was little difference in the other types of weaves with the possible exception of 1-2 weaves in Zone III, which were slightly fewer for the signs spaced 800 feet.

The electronic sign panel speed data in Table 21 do not show any particular variable to have an advantage over the others. In the few instances where there are differences in the 1.5-3.0 mph range, the electronic sign panel "apart" exhibits the lower values.

During testing of the signing schemes involving the electronic sign panel, several runs were made through the test site in the flow of traffic. In all runs it was observed that the sign panel was glaringly visible at distances up to a mile, which demonstrates that it warns motorists of an unusual road situation well in advance of men working and lane closure signs. In addition, the panel did a good job of channeling traffic into the proper lanes well in advance of the work area.

It should be noted that once during testing there was a sudden rainstorm that prevented the immediate opening of a closed right lane. It is the opinion of the author that the high intensity arrow did an admirable job of directing the motorist away from a closed lane in an almost blinding storm.

Speed Limit

An indication of the influence of speed limit signs on weaving and speeds may be obtained from Table 22. As can be noted from the total and total weighted weaves for each of the three conditions, the schemes without speed limit signs resulted in fewer weaves. It should be noted that in some cases where speed limit signs were not erected the number of signs was reduced to two or three, which possibly reduced the number of weaves.

SUMMARY OF SPEED DATA FOR ELECTRONIC SIGN PANEL
RIGHT LANE CLOSURE

Sign Condition	Mean Speeds A	B	C	Variables
Double Indication Orange Signs (1) Orange Cones	57.5	61.0	52.0	Close
	56.8	58.9	52.3	Apart
Double Indication Orange Signs (2) Orange Cones	57.0	59.5	50.7	Close
	57.0	58.8	53.2	Apart
Double Indications Orange Signs (3) Orange Cones	58.9	57.9	52.7	Close
	57.5	58.1	53.8	Apart
Single Indication Orange Signs (4) Orange Cones	60.9	62.2	55.1	Close
	60.7	59.0	56.0	Apart
Double Indication Orange Cones (5) Orange Signs	58.9	57.9	52.7	Signs at 800'
	56.0	61.4	50.3	Signs at 1000' - 1500'
	57.5	61.0	52.0	Signs at 1000' - 1500'
Double Indications Orange Cones (6) Orange Signs	56.9	58.2	53.7	Signs at 800'
	56.8	58.9	52.3	Signs at 1000' - 1500'

(1) Signs 1000' - 1500' 1 Sign Panel Moved
(2) High Level in Work Area; Panel Moved
(3) Sign Panel and Signs Moved
(4) Sign Panel and Signs Moved
(5) Sign Panel Stationary at End of Taper; Sign Spacing Varied
(6) Sign Panel Stationary at Beginning of Taper; Sign Spacing Varied

* Sign Sequences Changed; "Speed Limit 45" Before "Right Lane Closed Ahead"

TABLE 22

SUMMARY OF MEAN SPEEDS AND WEAVES FOR SHOULDER AND MOWING OPERATIONS - SPEED LIMIT VS. NO SPEED LIMIT

Sign Conditions	Weaves - %			Mean Speeds			Variables
	Total	Weighted Total	2 - 1	A ****	B	C	
Shoulder Operations Single Indication Yellow Signs (1)	25.7	90.7	14.5	58.7	64.2	54.8	Speed Limit
	23.5	74.0	13.0	62.0	66.9	58.4	No Speed Limit
Mowing Operation Single Indication Yellow Signs (2)	19.2	57.4	8.0	61.9	63.6	60.1	*Speed Limit
	18.7	52.9	8.0	61.0	64.7	61.4	**Speed Limit
	17.2	48.4	8.7	60.6	65.0	61.4	*** No Speed Limit
Mowing Operations Single Indication Orange Signs (3)	18.1	54.4	7.8	63.8	60.9	60.4	*Speed Limit
	20.5	59.7	7.3	61.5	59.9	61.4	** Speed Limit
	20.4	57.8	9.5	61.8	60.5	61.1	*Speed Limit
	16.8	49.3	7.4	62.1	64.2	63.5	*** No Speed Limit
	13.8	39.9	6.1	62.3	62.5	59.8	*** No Speed Limit

*4 Signs: Reduce Speed head; Speed Limit 45; Mowing Operations Ahead; End Mowing Operations.
**5 Sign: Mowing Operations Ahead; Reduce Speed Ahead; Speed Limit 45; Men Working; End Repairs
**2 Signs: Mowing operations Ahead; End Mowing Operations
*** Are data taken in 1968

Referring to the mean speeds for shoulder operations, the speeds were reduced by 2.7 mph at point B and 3.6 mph at point C for speed limit signs erected in conjunction with the other signs. For condition 2, the differences in speed limit versus no speed limit were small.

Speed limit signs produced a decrease in speeds at point B for condition 3. However, this difference was not witnessed at point C, where speeds varied for no reason.

Referring to the percent weaves in Table 23, there is very little difference in total, total weighted, and 1 - 2 weaves for condition 1; however, the 1 - 2 weighted and 1 - 2 Zone III weaves were fewer for the schemes with the speed limit sign included. Results for condition 2, which compared schemes including advisory speed limit signs with those including regular speed limit signs, indicated that the regular speed limit signs produced fewer weaves in all cases. It should be noted that the signing scheme incorporating the advisory speed limit sign had one less sign than the other scheme as a result of the omission of the "reduce speed ahead" sign. The use of fewer signs means that the initial warning signs are closer to the work site, and therefore induce the motorist to maneuver closer to the work site.

The weaves for the different positions of the "speed limit 45" and "right lane closed ahead" signs are under condition 3. Here, the sequence having the "speed limit" after the "right lane closed ahead" sign reflected the fewer weaves for the majority of the types considered. This result is most likely a function of the "right lane closed ahead" sign being closer to the work site, which allowed the motorists to receive the lane closure message later, and thereby required more weaving within the test site.

The speed limit versus no speed limit data are shown in Table 24. Under condition 1 there were speed decreases of 2.3 and 3.1 mph respectively for points B and C when "speed limit 45" signs were included. A comparison of the "advisory 45" and "advisory 55" speed limit signs with "speed limit 45" signs for condition 2 revealved a definite speed reduction at points B and C for the "speed limit 45" sign. It is noted that the sign background for the advisory speed limit signs was either yellow or orange. There was little difference in speeds for the positions of the "speed limit 45" sign in relation to the "right lane closed ahead" sign for condition 3 with the exception of point C, where there was a 1.7 mph difference.

Sign Message

Table 25 shows the comparison of weaves for changes in message for the two initial warning signs. Under conditions 1 through 3 it is apparent that with the "lane closed, repairs ahead" sign placed first there were fewer weaves than with the "repairs ahead" sign first. It should be noted that conditions 1 through 3 had single indications. Condition 4, with double indications, however, did not exhibit such a substantial difference between the "lane closed, road work ahead" and "repairs ahead" signs as did conditions 1 through 3, assuming that the difference between "repairs ahead" and "road work ahead" signs was insignificant. This finding may be explained by the influence of single as compared to double indications. When a motorist observes the initial sign "lane closed" and notes signs only on one side, he may assume that this is the side on which the lane is closed and automatically maneuvers accordingly, whereas, for double indications right lane closure may not be apparent.

TABLE 23

SUMMARY OF WEAVE DATA FOR SPEED LIMIT VS.
NO SPEED LIMIT — RIGHT LANE CLOSURE

Signing Conditions	Percent Weaves						Variables
	Total	Total Weighted	1 - 2	1 - 2 Weighted	2-1 + 2-3 + 3-2	1 - 2 Weaves Zone III	
Double Indications Orange Signs Orange Cones HLWD (1) Trailer Apart	43.0	106.8	21.2	40.3	66.5	2.9	Speed Limit 45
	42.5	110.4	23.7	52.0	58.8	6.0	No Speed Limit
Double Indications Orange Signs Orange Cones (2) Trailer Apart	45.0	115.9	25.3	55.3	58.9	6.4	Advisory Speed Limit 45
	42.3	108.3	23.7	51.6	56.7	5.3	Advisory Speed Limit 55
	37.3	77.6	21.1	36.1	41.2	3.6	Speed Limit 45
Double Indications Orange Signs Orange Cones (3) Early Warner Close	48.6	108.4	23.7	44.7	63.8	4.5	Speed Limit 45, 2nd Sign*
	40.1	94.0	16.5	30.7	63.0	4.1	Speed Limit 45, 3rd Sign**

* First 4 signs: Repairs Ahead; Reduce Speed Ahead; Speed Limit 45; Right Lane Closed Ahead

** First 4 signs: Repairs Ahead; Right Lane Closed Ahead; Reduce Speed Ahead; Speed Limit 45.

TABLE 24

SUMMARY OF SPEEDS FOR SPEED LIMIT VS.
NO SPEED LIMIT — RIGHT LANE CLOSURE

Sign Conditions	Mean Speeds			Variables
	A	B	C	
Double Indications (1) Orange Signs Orange Cones & HLWD Trailer Apart Signs Expanded	57.4	57.7	53.3	Speed Limit 45
	57.1	60.0	56.4	No Speed Limit
Double Indications Orange Signs Orange Cones (2) Trailer Apart	57.5	60.0	56.8	Advisory Speed 45
	58.2	58.8	56.1	Advisory Speed 55
	60.9***	56.5	51.6	Speed Limit 45
Double Indications Orange Sign Orange Cone (3)	56.0	61.4	50.3	Speed Limit 45 2nd Sign
	57.5	61.0	52.0	Speed Limit 45; 3rd Sign

* First 4 signs: Repairs Ahead; Reduce Speed Ahead; Speed Limit 45; Right Lane Closed Ahead

** First 4 signs: Repairs Ahead; Right Lane Closed Ahead; Reduce Speed Ahead; Speed Limit 45.

*** 1968 Data

TABLE 25

SUMMARY OF WEAVES FOR DIFFERENT SIGN MESSAGES-RIGHT LANE CLOSURE

Signing Conditions	Percent Weaves						Variables
	Total	Total Weighted	1 - 2	1 - 2 Weighted	2-1 + 2-3 + 3-2 wtd.	1 - 2 Weaves Zone III	
Single Indications Yellow Signs Orange Cones Trailer Apart (1)	23.6	58.4	6.4	10.9	47.6	1.2	*
	33.3	80.9	14.0	22.9	58.1	2.2	****
Single Indications Yellow Signs Yellow Cones Trailer Apart (2)	33.1	82.0	12.3	22.6	59.3	3.2	*
	52.7	108.8	33.1	58.3	50.5	8.0	****
Single Indications	40.9	86.3	19.9	31.5	54.8	2.7	****
Orange Signs	25.7	59.8	8.3	9.8	50.8	1.5	**
Orange Cones Trailer Apart(3)	23.9	60.3	6.2	10.0	50.3	1.3	*
Double Indications	47.8	125.4	28.5	62.3	63.0	8.5	****
Yellow Signs Yellow Cones Trailer Close (4)	51.4	101.0	27.3	42.6	58.4	4.0	***
Single Indications	32.3	72.4	17.9	35.0	37.4	4.9	****
Yellow Signs Yellow Cones Trailer Close (5)	37.8	72.2	20.1	29.1	43.1	2.4	

* (1) Lane Closed and Repairs Ahead (2) Keep Left
** (1) Lane Closed and Repairs Ahead (2) Right Lane Closed Ahead
*** (1) Lane Closed and Road Work Ahead (2) Keep Left
**** (1) Repairs Ahead (2) Right Lane Closed Ahead

Under condition 5, which was identical to condition 1 with the exception of having single indications, there were no appreciable differences in weaves.

From the mean speeds in Tables 26, there appears to be little difference within the conditions, with the possible exception of conditions 1 and 2, where speeds are lower at point B for the sign conditions having the initial message "lane closed, repairs ahead" as opposed to "repairs ahead." It is interesting to note that the results at point C show the opposite of this condition to be true. The differences are not as large, however, at point B.

TABLE 26

SUMMARY OF SPEED DATA FOR DIFFERENT SIGN MESSAGES-RIGHT LANE CLOSURE

Signing Conditions	Mean Speeds			Variables
	A	B	C	
Single Indications	56.3	55.0	57.1	*
Yellow Signs Orange Cones (1) Trailer Apart	62.0	58.5	56.5	****
Single Indications	56.8	56.3	59.0	*
Yellow Signs Yellow Cones Trailer Apart (2)	62.5	60.4	58.7	**** 1968
Single Indications	61.1	58.4	55.7	****
Orange Signs	59.5	58.3	57.9	** 1968-1969
Orange Cones Trailer Apart (3)	58.7	57.4	56.7	* 1968-1969
Double Indications	63.4	58.8	51.6	**** 1968
Yellow Signs Yellow Cones Trailer Close (4)	61.5	58.4	52.5	*** 1968
Single Indications	62.8	61.5	54.6	* 1968
Yellow Signs Yellow Cones Trailer Close (5)	62.2	61.1	55.2	*** 1968

* (1) Lane Closed and Repairs Ahead (2) Keep Left
** (1) Lane Closed and Repairs Ahead (2) Right Lane Closed Ahead
*** (1) Lane Closed and Road Work Ahead (2) Keep Left
**** (1) Repairs Ahead (2) Right Lane Closed Ahead

Sign Spacing

An indication of the influence of sign spacing on weaving for right lane closures may be obtained from Table 27. The signs extended (1000'-1500') caused fewer weaves in the majority of cases. This could be a result of the initial signs being placed prior to Zone I, which thereby induced motorists to weave before entering Zone I and not be counted. This would, however, eliminate some weaving closer to the work site. This does not infer that signs may be placed 3 to 4 miles in advance of a work site because in such a situation there would be no continuity of sign message, lane taper and trailer or sign panel. Very little difference was noted in work site speeds for the sign spacings shown in Table 28.

TABLE 27

SUMMARY OF WEAVING FOR SIGN SPACING—RIGHT LANE CLOSURE

Signing Conditions	Percent Weaves						Variables
	Total	Total Weighted	1-2	1-2 Weighted	2-1+2-3+ 3-2 Wtd.	1-2 Zone III	
Single Indications Orange Cones	31.6	68.8	14.5	20.3	42.5	2.7	1000-1500 ft.
Yellow Signs (1) Trailer Close	45.1	108.9	26.4	54.5	54.4	9.7	800 ft.
Single Indications Orange Cones	36.5	69.1	18.8	28.7	40.4	3.7	1000-1500 ft.
Orange Signs (2) Trailer Close	38.4	81.0	22.1	36.6	44.5	3.4	800 ft.
Single Indications Orange Cones	35.6	88.8	14.0	25.8	62.7	2.2	1000-1500 ft.
Orange Signs (3) Trailer Close	42.2	88.9	20.7	31.9	57.0	2.9	800 ft.
Double Indications Orange Cones	33.8	77.0	11.9	20.5	56.6	2.2	1000-1500 ft.
Orange Signs (4) Early Warner Apart	40.9	87.4	19.6	28.0	55.2	1.4	800 ft.

TABLE 28

SUMMARY OF SPEEDS FOR SIGN SPACING—RIGHT LANE CLOSURE

Signing Conditions	Speeds			Sign Spacing
	A	B	C	
Single Indications Orange Cones	69.9	60.5	56.2	1000' 1500'
Yellow Signs (1) Trailer Close	63.5	63.0	55.7	800'
Single Indications Orange Cones	63.2	60.8	55.9	1000' 1500'
Orange Signs (2) Trailer Close	59.1	59.6	57.1	800'
Single Indications Orange Cones	59.5	61.9	57.2	1000' 1500'
Orange Signs (3) Trailer Close	59.5	57.3	58.1	800'
Double Indications Orange Cones	56.8	58.9	52.3	1000' 1500'
Orange Signs (4) Early Warner Apart	55.6	58.7	53.9	800'

Total Signing Schemes

An attempt was made to arrive at the one best signing condition for each of the maintenance operations tested. Comparisons were made on the basis of total, total weighted, and 1-2 weighted weaves for each scheme. Table 29 shows the condition comparisons made for mowing operations in the order of desirability, the best being first.

TABLE 29

TEST SCHEMES COMPARISON—MOWING OPERATIONS

Signing Condition	% Weaves			Mean Speed		Comments
	Total	Total Weighted	1-2 Weighted	B	C	
Single Indications Orange Signs (1) Two Signs	13.8	39.9	15.1	62.5	59.8	Two signs: one mile apart 1) Mowing Operations Ahead 2) End Mowing Operations
Single Indications Orange Signs (2) Two Signs	16.7	49.2	17.8	63.9	61.5	Two signs: 1600 feet apart 1) Mowing Operations Ahead 2) End Mowing Operations
Single Indications Orange Signs (3) Two Signs	16.8	47.3	18.3	65.0	61.4	Two signs: one mile apart 1) Mowing Operations Ahead 2) End Mowing Operations HLWD in work area

As can be noted in Table 29, the best condition had no speed limit sign and the two orange signs, "mowing operations ahead" and "end mowing operations," which were placed one mile apart.

As noted in Table 30, which shows the three best signing conditions for shoulder operations, there is very little difference between the conditions. Sign condition 1 had double orange signs and a speed limit sign, whereas condition 2 had similar signs with only single indications and high level warning devices in the work area. Condition 3 had a minimum of 3 yellow signs, no speed limit signs, and the signs were placed on only one side of the road.

TABLE 30

SCHEME COMPARISON—SHOULDER OPERATIONS

Signing Conditions	Weaves			Mean Speed		Comments
	Total	Total Weighted	1-2 Weighted	B	C	
Double Indications Orange Signs Speed Limit (1)	19.9	60.9	25.1	60.5	58.3	Signs 1) Reduce Speed Ahead 2) Speed Limit 45 3) Repairs Ahead 4) Men Working 5) End Repairs
Single Indications Orange Signs Speed Limit (2)	20.7	60.6	27.3	63.0	59.6	Signs 1) Reduce Speed Ahead 2) Speed Limit 45 3) Shoulder Work Ahead 4) End Shoulder Work HLWD in work area
Single Indications Yellow Signs No Speed Limit (3)	20.1	61.6	32.9	66.7	57.9	Signs 1) Repairs Ahead 2) Men Working 3) End Repairs

The best signing schemes tested for the right lane closure are shown in Table 31. It should be noted that only schemes with double indications were considered because of the reasons cited earlier. The three best schemes all had orange signs, orange cones and sign panels (condition 1 and 2) or trailer "apart" (condition 3). Signs were extended (1000-1500') in condition 1, whereas they were regularly spaced (800') for conditions 2 and 3.

TABLE 31

SCHEME COMPARISON—RIGHT LANE CLOSURE
WITH DOUBLE INDICATIONS

Signing Condition	Weaves			Mean Speeds		Comments
	Total	Total Weighted	1-2 Weighted	B	C	
Double Indications Orange Signs Orange Cones Sign Panel Apart Signs Extended (1000'-1500') (1)	33.8	77.0	20.5	58.9	52.3	Signs 1) Repairs Ahead 2) Right Lane Closed Ahe 3) Reduce Sp Ahead 4) Speed Lim 45 5) Electronic Sign Pane 6) End Repai
Double Indications Orange Signs Orange Cones Sign Panel Apart Signs (800') (2)	39.2	76.6	27.0	58.2	54.8	Signs Same as abo except signs extended
Double Indications Orange Signs Trailer Apart Signs (800') (3)	37.3	77.6	36.1	56.5	51.6	Signs Same as (2) except Sign Trailer repl electronic si panel

ACCIDENT SURVEY

In view of the limited data available on work site accidents throughout Virginia, a work site accident survey was conducted during the 1968 construction and maintenance seasons for the six month period May through October. Prior to the survey, a summary was made of all 1966 rural and urban "under repair" accidents in Virginia to get an indication of the adequacy of existing procedures for reporting such accidents. It was discovered that the existing accident data for work sites, coded as "under repair", were inadequate for the identification of hazards associated with road work activities. Because of the limitations of the existing accident report data, a new one (see Appendix B) was devised for the survey. The survey included not only highway personnel, but also the state police and several urban county forces. It was the intent of this survey to have all accidents occurring at temporary work site areas reported by Department personnel. The accidents were reported on the work site accident forms sent to the various agencies mentioned.

The identification of the factors contributing to work site accidents was extremely difficult because of the short survey period. The 688 survey forms returned did not include sufficient data to permit pinpointing a specific cause for each accident since in many cases it was difficult to determine the exact cause. In addition, the survey information was insufficient to provide an overall picture of problem areas.

Table 32 is a compilation of various data taken from the 6-month survey.

TABLE 32

SUMMARY OF ACCIDENT DATA

	Construction	Construction Equipment	Maintenance	Total
Total Accidents	513	74	93	680
Persons Killed	17	0	5	22
Persons Injured	242	18	57	317
Property Damage	$375,540	$53,785	$80,370	$509,695

This information does reveal the fatalities, injuries, and property damage for construction and maintenance activities.

Surveys of this nature are difficult because of the limited data in the accident files; however, with improved accident reporting procedures and a larger inventory of data, the factors contributing to work site accidents could be identified. In any case, the survey proved helpful in bringing to light some of the problems related to the gathering of accident data and the experience may prove helpful in future surveys of this type.

TEMPORARY TRAFFIC CONTROL POLICIES AND REGULATIONS

There are no Virginia statutes that relate strictly to the protection of persons required to work on or near roadways. Actual accident prevention procedures are ordinarily developed by individual agencies or departments, and published in their respective safety manuals. These manuals describe traffic control methods used by the issuing agencies.

Whenever it is deemed appropriate, a flagman is utilized to warn motorists well in advance of the lane closure area. Local agencies ordinarily specify certain wearing apparel for flagmen, such as highway orange vests, and certain techniques to be used by them. When local contractors do repair work, many states require that they appoint one man to maintain the protective devices in good condition.

The present work site accident experience is convincing evidence of the need for the best protection possible. Effective protection can only be afforded by comprehensive accident prevention research and statewide standardization of safety techniques developed from the research.

CONCLUSIONS

The conclusions listed below reflect the effectiveness of the various maintenance operation signing conditions tested in that they are based on the observed maneuvers and speeds of motorists passing through the signed work area and the opinions of the research crew. The accident potential of various temporary signing conditions now in use may be reduced by incorporating the corrective measure noted below. It is hoped that these measures will also be applicable to other types of signing conditions for work site operations.

(1) For the variable of flags versus no flags, very little difference was found in speeds; however, there were slightly more weaving maneuvers for the signs with flags. Based on the slight differences found in the number of weaves and speed, coupled with the alerting qualities of signs with flags, it was decided that flags should be included in the signing conditions.

(2) The effect of using signs with different colored backgrounds, orange or yellow, was minimal, i.e. yellow was better in some cases whereas orange was better in others. Yellow signs did induce fewer weaves. Orange signs had better attention commanding qualities as determined by runs through the test site; however, the message legibility of these signs was questionable.

(3) The use of orange cones and high level warning devices induced lane weaving. When used for delineation of the work area for mowing and shoulder operations high level warning devices had the effect of reducing traffic speeds. Orange cones had a definite advantage over

the other devices in eliminating lane weaves, and persuaded earlier weaving out of the eventually closed lane for right lane closures. Test runs by the observers revealed the orange cones to have good color contrast with the pavement and background and to provide a highly visible lane closed taper line.

Speeds within the work area were consistently lower for orange cones than yellow cones; however, the difference may not be significant.

(4) In tests of signs on one side of the road versus signs on both sides, the latter induced slightly fewer weaves for shoulder operations. Speeds were inconsistent, with no appreciable difference being noted between the two conditions.

For right lane closures, one-side signing induced fewer weaves, but a lesser reduction in speeds.

(5) In tests of the effect of placing a trailer bearing a lane closed sign at the beginning of the lane closed taper as opposed to placing it at the end of the taper, it was found that for the former position lane weaves were fewer and that they were made earlier.

Speeds did not seem to be appreciably influenced by the position of the trailer.

(6) The use of an electronic sign panel with a sequentially moving arrow induced fewer and earlier lane weaves as compared with the "LANE CLOSED" trailer. There was very little difference between the effects of the two devices on speed. In tests of the electronic sign panel at the beginning of the lane closed taper and at the end, the panel generally induced fewer lane weaves when placed at the former position. Also, in some instances, it was more effective in causing speed reduction at this position.

On the basis of test runs made through the work site during testing and the opinions given in the questionnaire, the electronic sign panel does an admirable job of channeling traffic into the proper lanes well in advance of the work area.

(7) For mowing and shoulder operations, signing schemes without a speed limit sign induced fewer weaves than did those with the sign. For the right lane closure, advantages were noted with speed limits for inducing earlier weaving out of the closed lane. The comparison of advisory speed limit signs and the regular speed limit signs indicated that the regular signs induced fewer weaves.

Speeds were generally reduced as a result of the use of the speed limit sign for shoulder operations; however, this did not hold true for mowing operations, where the differences were small. Speed decreases at the work area were found for inclusion of speed limit signs in right lane closure schemes, as the regular speed limit sign was more effective in reducing speed than was the use of no speed limit sign or advisory speed limit signs.

(8) When the "LANE CLOSED, REPAIRS AHEAD" sign was the initial sign, as compared with "REPAIRS AHEAD", there were fewer weaves, with signs on only one side of the road; for signs on both sides there was little difference. Also minor differences in speed were noted when comparing the two initial signs mentioned above.

(9) It was noted that sign spacing influenced weaving, with fewer weaves being made when signs were extended (1000 - 1500 feet) as opposed to the regular spacing (800 feet). Work site speeds varied little between the two spacings.

(10) The best signing schemes for mowing operations, based on weaves, had two orange signs (one side only), "MOWING OPERATIONS AHEAD" and "END MOWING OPERATIONS."

For shoulder operations, there was very little difference between the three best schemes. The scheme specifying signs on both sides of the road and the use of orange signs and a speed limit sign induced the fewest number of weaves.

Considering only the double signing for a right lane closure, and the weaving criterion, the two best schemes both incorporated orange signs, orange cones, and the electronic sign panel placed at the beginning of the lane taper. The only difference was the spacing between signs. The best scheme had a spacing of 1000 - 1500 feet, whereas the other spacing was 800 feet.

RECOMMENDATIONS

Based on the results of this study it is felt that implementation of the following recommendations will reduce the accident potential in the maintenance operations cited on divided, limited access highways.

Mowing Operations

For mowing operations, it is recommended that four orange signs be used, two signifying that mowing operations may be expected ahead (two adjacent signs, one on each side of the highway facing traffic) and two signifying that mowing operations have ended (two adjacent signs, one on each side of the highway). These signs encompass the area being mowed. As a result of the distance between signs and the close proximity of the tractor to the highway (sometimes crossing it), it would be desirable to make the tractor and driver as conspicuous as possible.

Shoulder Operations

For shoulder operations, it is recommended that a signing scheme using double signing with orange background signs and a speed limit sign be used. The initial signs should indicate that road work may be expected ahead. They should be followed by the speed limit signs, and then signs indicating an end to road work.

Right Lane Closure

For a right lane closure, it is recommended that orange background signs and reduced speed limit signs be used on both sides of the roadway. The initial signs should inform the motorist that road work and a lane closure may be expected ahead. These signs should be followed by the speed reduction signs, which in turn should be followed by jumbo orange cones forming a lane closed taper and extending along the work area. An electronic sign panel with an illuminated high intensity sequential arrow indicating the direction in which traffic should maneuver to avoid the closed lane should be placed at the beginning of the taper. The last sign in the series should indicate an end to the road work.

Sign spacing for the initial signs should be 1000 feet, with 1500 feet being allowed for the spacing between the sign ahead of the taper and the beginning of the taper.

The lane closed taper should be 800 feet long with cones spaced at 40 feet intervals.

Future Research

Future endeavors should include the testing of temporary sign layouts, other than those considered here, for maintenance and construction operations. For example, mobile operations such as centerline painting have a high exposure to traffic and are therefore extremely hazardous.

Also, laboratory testing procedures could be developed to analyze the visual detectability and attention gaining value of various temporary signing devices.

Of course, because of ever increasing traffic, a continuing effort is necessary for evaluating new methods and devices for work site protection.

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APPENDIX A

SIGNS AND DEVICES USED IN TESTING SCHEMES

TABLE A-1

DESCRIPTIVE DATA ON SIGNS

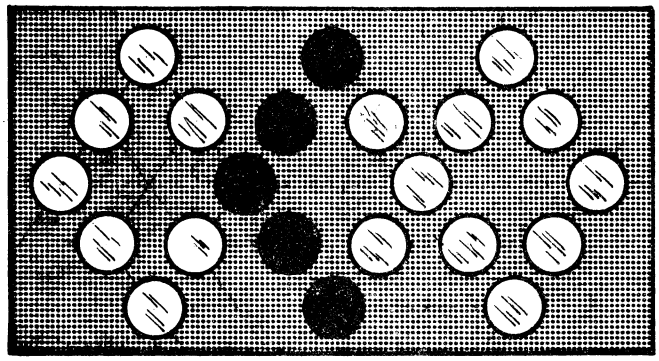
	Message	Size	Color	Description
Signs Used in Mowing Operation	Men Working	48" x 48"	Orange	** Diamond Shape
	Mowing Operation Ahead	48" x 48"	Orange	** Diamond Shape
	Mowing Operation Ahead	48" x 48"	Yellow	* C - 23
	Reduce Speed Ahead	48" x 60"	White	* R - 12 E
	Speed Limit 45	48" x 60"	White	* R - 5 E
	End Repairs	48" x 48"	Yellow	* C - 8
	End Mowing Operation	48" x 48"	Orange	** Diamond Shape
Signs Used in Shoulder Closure	Repairs Ahead	48" x 48"	Yellow	* C - 7
	Men Working	48" x 48"	Yellow or Orange	** Diamond Shape
	Shoulder Work Ahead	48" x 48"	Yellow or Orange	** Diamond Shape
	Reduce Speed Ahead	48" x 60"	White	* R - 12 E
	Speed Limit 45	48" x 60"	White	* R - 5 E
	End Shoulder Work	48" x 48"	Yellow or Orange	** Diamond Shape
	End Repairs	48" x 48"	Yellow or Orange	* C - 8
Signs Used in Right Lane Closure	Lane Closed	54" x 36"	White	** Rectangular
	Road Work Ahead	48" x 48"	Yellow	** Diamond Shape
	Repairs Ahead	48" x 48"	Yellow or Orange	* C - 7
	Right Lane Closed Ahead	48" x 48"	Yellow or Orange	* C - 38 E
	Keep Left	48" x 48"	White	* R - 21 B
	Reduce Speed Ahead	48" x 60"	White	* R - 12 E
	Speed Limit 45	48" x 60"	White	* R - 5 E
	Maximum Safe Speed 45	48" x 60"	Orange	** Rectangular
	Maximum Safe Speed 55	48" x 60"	Orange	** Rectangular
	End Repairs	48" x 48"	Yellow or Orange	* C - 8
	End Repairs	48" x 36"	Yellow	* C - 6

* Virginia Manual of Uniform Traffic Control Devices for Streets and Highways

** Special Sign Message

Signs mounted on tripods. Bottom of signs were 4 feet from top of pavement. Signs were 10 feet from edge of pavement.

Lane Closed Trailer
Size: 77" x 78"
Color: Yellow or Orange

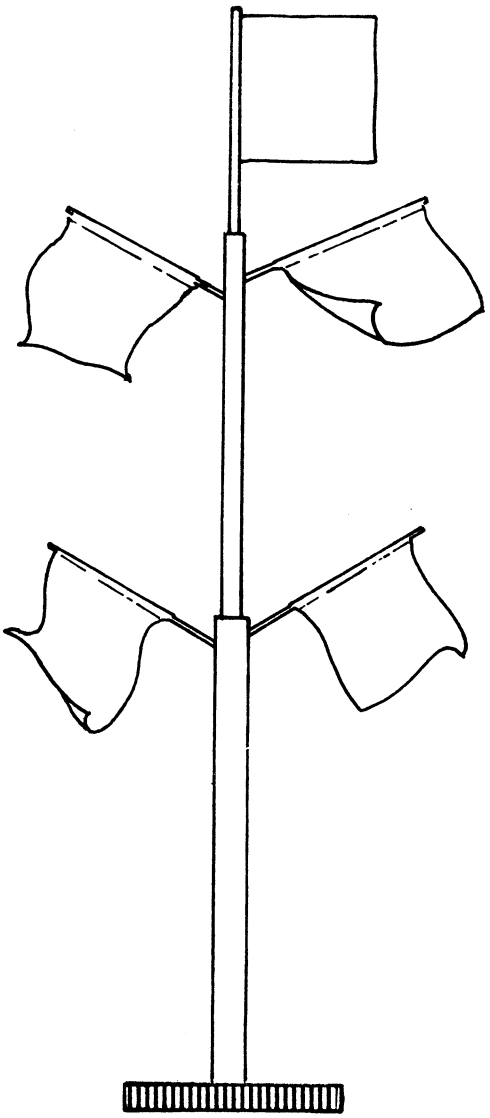


Electronic Sign Panel
Height: 13'-6" above roadway
Size: 76" x 40"
Lamps: 22, 12 volts, 35 watts

Sequential moving lighted arrows move across panel left and right. The outside arrow heads are lighted and the four center bars flash simultaneously.

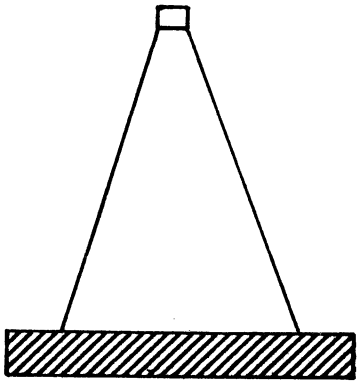
Figure A-1. Devices used in right lane closure.

High Level Device



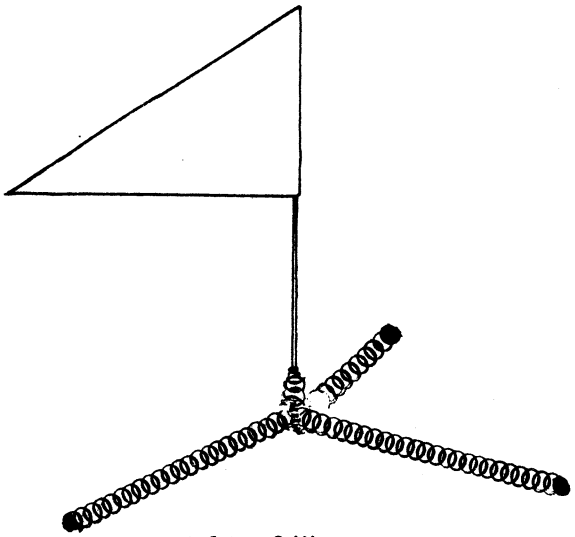
Height: 9'
Color: Yellow Staff
Orange Flags
Black Base

Cone



Height: 36"
Cone Spacing: Approximately 40'
Color: Yellow or Orange
Black Base

Octopus



Height: 24"
Color: Orange Flags

Figure A-2. Devices used with maintenance operations signing schemes.

APPENDIX B

SUMMARY OF "UNDER REPAIR" ACCIDENTS IN VIRGINIA DURING 1966

In order to obtain an accurate indication of under repair accidents for both rural ınd urban locations, the accident files of the Virginia State Police were used, since Highway Department records are primarily for rural accidents.

One major weakness of this rural summary data is that the interstate roads are ncluded in the primary classification. A review of the 1966 data cards revealed that he 1004 rural accidents were divided into the following categories:

nterstate	Primary	Secondary	No Route	Total
205	562	180	57	1004

Table B-1 indicates the urban under repair accidents in cities of 10,000 or more ɔopulation. Arlington County is also included. Table B-2 indicates the location of all ınder repair fatal accidents in 1966. Table 3 indicates the Highway District location for he 1004 accidents.

To obtain an idea of the variation of under repair accidents over a longer period of ime, the Virginia Traffic Crash Factor Reports from 1952-1966 were summarized and ıre presented in Table B-4. An urban breakdown was not given in these reports so the ırban data were obtained by subtracting the rural data from the total Virginia data. It ɔan be noted that the under repair accidents per year vary from 0.72 to 1-1.5% of the ɔtal accidents in the state.

Table B-5 shows the under repair fatal accidents from 1952-1966 inclusive.

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TABLE B-1

UNDER REPAIR ACCIDENTS IN VIRGINIA CITIES

1966

City	Population	No.		
Norfolk	305,872	51		
Richmond	219,958	0	4 >	100,000 pop.
Portsmouth	114,773	15		
Newport News	113,662	9		
Roanoke	97,110	84		
Alexandria	91,023	138	4 >	50,000 pop.
Hampton	89,258	1		
Lynchburg	54,790	2		
Danville	46,577	2		
Petersburg	36,750	122	3 >	25,000 pop.
Charlottesville	29,427	2		
Staunton	22,232	1		
S. Norfolk	22,035	0		
Martinsville	18,793	13		
Hopewell	17,895	1		
Bristol	17,144	6		
Salem	16,058	16		
Waynesboro	15,694	112		
Winchester	15,110	3		
Fredericksburg	13,639	5	17 >	10,000 pop.
Fairfax	13,585	11		
Suffolk	12,609	7		
Harrisonburg	11,916	15		
Vienna	11,440	1		
Covington	11,062	11		
Pulaski	10,469	9		
Falls Church	10,192	28		
Colonia Heights	10,115	23		
Arlington County	163,401	36	(urban area)	
	TOTAL	724		

TABLE B-2

LOCATIONS OF UNDER REPAIR FATAL ACCIDENTS IN VIRGINIA

1966

RURAL

County	Route
Amherst	29
Campbell	29
Caroline	301
Dinwiddie	460
Fairfax	95
Henrico	691
Nansemond	189
Rockbridge	60

URBAN

Petersburg	N/A
Waynesboro	N/A
West Point	N/A
Arlington	N/A

N/A - No route identification

TABLE B-3

RURAL UNDER REPAIR ACCIDENTS IN VIRGINIA

1966

Highway District	No. on Interstate	No. on Primary	No. on Secondary	No Route	Total
Culpeper	191	81	69		341
Richmond	4	105	46		155
Salem	—	84	20		104
Lynchburg	—	61	8		69
Suffolk	—	85	8	57	93
Bristol	2	72	10		84
Fredericksburg	4	28	5		37
Staunton	4	46	14		64
TOTAL	205	562	180	57*	1004

* This includes accidents in cities > 3,500 population which the state police include as urban.

TABLE B-4

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SUMMARY OF UNDER REPAIR ACCIDENTS
1952-1966

YEAR	No. Under Repair Accidents (a) All Va.	(b) Rural Va.	(a-b) Urban Va.	Total Accidents in Virginia	% *
1952	666	451	215	58,852	1.13
1953	568	375	193	59,432	.96
1954	592	327	265	58,866	1.01
1955	558	411	147	66,782	.84
1956	848	620	228	72,168	1.17
1957	866	531	335	70,261	1.23
1958	731	411	320	71,478	1.02
1959	667	423	244	75,126	.89
1960	574	363	211	80,323	.72
1961	881	724	157	85,508	1.03
1962	971	695	276	94,051	1.03
1963	1109	726	383	98,816	1.12
1964	1319	767	552	109,336	1.20
1965	1814	1016	798	111,179	1.63
1966	1763	1009	754	116,275	1.52

* Percent of total accidents which were under repair accidents.

TABLE B-5

UNDER REPAIR FATAL ACCIDENTS

1952-1966

YEAR	Under Repair Fatal Accidents (a) All Va.	(b) Rural Va.	(a-b) Urban Va.	Total	%
1952	9	7	2	960	.9
1953	10	8	2	904	1.1
1954	9	8	1	810	1.1
1955	8	7	1	879	.9
1956	11	9	2	830	1.3
1957	9	6	3	912	1.0
1958	8	7	1	861	.9
1959	7	6	1	850	.8
1960	4	4	0	756	.5
1961	5	4	1	856	.6
1962	15	15	0	974	1.5
1963	7	6	1	989	.7
1964	9	8	1	1050	.9
1965	16	13	3	1062	1.5
1966	13	10	3	1106	1.2

* Percent of total accidents which were under repair accidents.

Route _____ County _____ Date of Acci

DIAGRAM O

Describe the accident briefly (refer to vehicles by number)

9. As a result of your investigation of the location (not necessarily for this particular accident) do you have any suggested improvements which may increase the safety of the motorists or pedestrians within this section?

O Yes O No If yes, explain the improvement_____

10. Photographs — If available, submit photographs showing:

    a. Each approach to accident scene

    b. Scene of accident

11. Complete the work site accident diagram on the reverse side of this page in accordance with the following instructions.

Instructions

a. Show the location and type of all temporary and semipermanent traffic control devices (traffic signs, traffic cones, barrels, barricades, smudge pots, delineators, etc.) in place for the work site operation which are in advance of the approach direction of the vehicle involved in the accident.

NOTE:

Temporary devices — any traffic control device which is used for roadwork during daylight periods only, such as for maintenance operations.
Semipermanent devices — any traffic control device which is used for roadwork during a period of 24 hours or longer and possibly for days or even months as in the case of construction projects.

b. Indicate condition (P - Poor, F - Fair, G - Good, and E - Excellent) of all temporary and semipermanent work site devices.
c. Show the location of all equipment, personnel and material in the vicinity of the accident site and, if work is actually being performed in the immediate area, show what it is and its general location.
d. If construction is being performed on a road parallel to the roadway open to traffic, show its general location with respect to the accident. This particularly applies to the arterial divided highway system with parallel construction underway.
e. Show sight distances in both directions.
f. Number vehicles in accordance with brief description of accident.
g. Use solid line to show path before accident.
h. Use dotted line after accident.
i. Indicate distances to nearest intersection, bridge or fixed landmark.
j. Show pavement width, shoulder width and median width if applicable.
k. A typical diagram for a maintenance operation accident is shown on the back of the general instruction sheet.

11. Was traffic in the vicinity of the accident site being controlled by flagmen during the work site activity?

O Yes O No

If no, proceed to question 12.

(a) If yes, what were their duties?_____

(b) How were the flagmen equipped? (complete for each flagman, and check one or more if applicable)

Flagman No. 1	Flagman No. 2	Flagman No. 3	Flagman No. 4
O Flag	O Flag	O Flag	O Flag
O Stop-Go Paddle	O Stop-Go Paddle	O Stop-Go Paddle	O Stop-Go Paddle
O Orange Vest	O Orange Vest	O Orange Vest	O Orange Vest
O Helmet	O Helmet	O Helmet	O Helmet
O Lights	O Lights	O Lights	O Lights
O Other devices — (please specify)	O Other devices — (please specify)	O Other devices — (please specify)	O Other devices — (please specify)
_____	_____	_____	_____

(c) Were the flagmen performing their duties satisfactorily? O Yes O No

If no, explain _____

12. If flagmen were not controlling traffic near the accident site, should they have been?

O Yes O No If no, explain _____

13. Were any remedial measures taken as a result of this accident to prevent future accidents?

O Yes O No If yes, please specify_____

1. Date of Accident _____

2. Day of Week (circle one) SUN M T W T F SAT

3. Hour _____ AM _____ PM _____

4. Type of Activity or Situation (check one)

- O VDH Maintenance Operation
- O Construction Operation (Check one — O VDH or O Contractor)
- O Survey Party Operation
- O Utility Company Operation
- O Other _____ (please specify)

5. Please describe briefly the type of work being performed or roadwork situation:

_____

_____

_____

_____

6. Was any equipment, material or personnel used by the VDH, the private contractor, the utility company or other agency physically involved or related in any way to the accident?

O Yes O No If yes, complete the following:

	Describe equipment, material, or personnel	Used by (VDH, contractor, utility company, etc.)	Action of equipment or personnel if moving; location of equipment or personnel if stationary; or location of material
a.			
b.			
c.			
d.			

7. In your opinion, did the roadwork activity contribute in any way to the accident?

O Yes O No If yes, explain _____

_____

_____

8. Do you feel this accident could have been prevented by any change in the responsible agency's operations?

1. Highway District _____ 2. County or Town _____

3. Indicate distance in miles and tenths of mile from nearest city or town. Use two distances and two directions if necessary.

_____ Miles north
_____ Miles south
_____ Miles east
_____ Miles west

of

O limits of _____ City or Town

O center of

4. Accident happened on U. S. or State route number _____

At its intersection with _____ Name of intersecting street or route no.

or if

Not at intersection

_____ feet north of _____
_____ feet south
_____ feet east
_____ feet west

Nearest intersecting street, bridge, railroad crossing, underpass, numbered telephone pole or other identifying landmarks. Show exact distance using two directions and two distances if necessary.

5. Total Vehicles Involved _____ .

Total Persons Killed _____ .

Total Persons Injured _____ .

Estimated Amount of Property Damage $ _____ , (Total approximate vehicle and non-vehicle property damage).

6. Weather conditions (check one)

- O Clear
- O Cloudy
- O Fog
- O Mist
- O Raining
- O Snowing
- O Sleeting
- O Smoke-dust

7. Surface condition (check one)

- O Dry
- O Wet
- O Snowy
- O Muddy
- O Oily
- O Icy
- O Other _____ (please specify)

8. Surface type (check one)

- O Concrete
- O Blacktop
- O Brick
- O Gravel
- O Dirt
- O Other _____ (please specify)

9. Defects (check one)

- O Loose material
- O Holes, ruts, bumps
- O Soft or low shoulder
- O No defects

10. Light Conditions (check one) O Daylight O Darkness — street lighted

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K SITE ACCIDENT

For VDH Employees Only

Maintenance Activity Code No. _____

Construction Project No. _____

Indicate North by Arrow