EVALUATION OF ARROW PANEL DISPLAYS FOR TEMPORARY WORK ZONES

Final Report

STATE RESEARCH 304-131

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by

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16. Abstract

The Oregon Department of Transportation evaluated the effectiveness of a "sequentially flashing diamond" arrow panel display as advance caution warning in temporary work zones. This display was evaluated by comparing it with two others; the flashing line and flashing four-corner. In survey responses from 33 state Departments of Transportation, each display was rated about the same in terms of effectiveness.

Field trials using each display were conducted in work zones set up on highway shoulders at two locations in Oregon. Total evaluation time at each site was nine hours, divided into three, 3-hour test periods. Each display operated for one hour during the 3-hour period. Hourly average and 85th percentile speeds recorded during the tests were lower than corresponding hourly baseline speeds for all display modes. The greatest speed reductions (from baseline) for most 3-hour periods occurred when the diamond display was operating.

Motorists were surveyed about the three displays. People at a highway rest area were asked questions about the displays that were operating in the parking area. Over 70% of 274 respondents chose the diamond display as the most effective at getting their attention. However, 61% found the three displays confusing, particularly the line and the four-corner. Although there was evidence of confusion about the displays, 80% of the respondents said they would like to see the diamond used when work is taking place on Oregon highways.

The results of the field trials and motorist survey show considerable potential for the diamond display's use as an advance warning device in temporary work zones.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

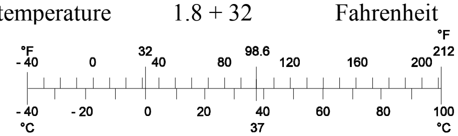
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
In	Inches	25.4	Millimeters	Mm
Ft	Feet	0.305	Meters	M
Yd	Yards	0.914	Meters	M
Mi	Miles	1.61	Kilometers	Km
		AREA		
In^2	Square inches	645.2	millimeters	mm^2
Ft^2	Square feet	0.093	meters squared	M^2
Yd^2	Square yards	0.836	meters squared	M^2
Ac	Acres	0.405	Hectares	Ha
Mi^2	Square miles	2.59	kilometers squared	Km^2
		VOLUME		
Fl oz	Fluid ounces	29.57	Milliliters	ML
Gal	Gallons	3.785	Liters	L
Ft^3	Cubic feet	0.028	meters cubed	m^3
Yd^3	Cubic yards	0.765	meters cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
Oz	Ounces	28.35	Grams	G
Lb	Pounds	0.454	Kilograms	Kg
T	Short tons (2000 lb)	0.907	Megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
Mm	Millimeters	0.039	inches	in
M	Meters	3.28	feet	ft
M	Meters	1.09	yards	yd
Km	Kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
Ha	Hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ML	Milliliters	0.034	fluid ounces	fl oz
L	Liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
G	Grams	0.035	ounces	oz
kg	Kilograms	2.205	pounds	lb
Mg	Megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

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DISCLAIMER

EVALUATION OF ARROW PANEL DISPLAYS F0R TEMPORARY WORK ZONES

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1.0 INTRODUCTION

1.1 PROBLEM STATEMENT

The Oregon Department of Transportation (ODOT) uses arrow panel displays as an advance warning device during mobile operations such as striping and sweeping, as well as for static operations like guardrail replacement or ditch maintenance. The purpose of the displays is to alert motorists when they are approaching temporary work zones (mobile or static) where work is taking place on the shoulder, or alongside the shoulder off the roadway. The arrow panel is a caution sign with a matrix of elements capable of either flashing and/or sequential displays.

There are four types of arrow panels that are discussed in the 2000 version of the Manual for Uniform Traffic Control Devices (MUTCD). These are listed below in Table 1.1.

Table 1.1: Arrow Panel Types

Panel Type	Minimum Size	Minimum Legibility Distance	Number of Elements
A	1,200 x 600 mm (48 x 24 in)	0.8 km (1/2 mi)	12
B	1,500 x 750 mm (60 x 30 in)	1.2 km (3/4 mi)	13
C	2,400 x 1,200 mm (96 x 48 in)	1.6 km (1 mi)	15
D	None*	0.8 km (1/2 mi)	12

*Length of arrow equals 1,200 mm (48 in), width of arrowhead equals 600 mm (24 in).

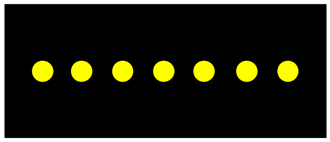
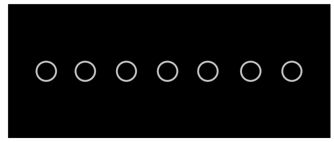
The 2000 MUTCD suggests that the four arrow panel types should be used in the following situations.

- Type A arrow panels are appropriate for use on low-speed urban streets.
- Type B arrow panels are appropriate for intermediate-speed facilities and for maintenance or mobile operations on high-speed roadways.
- Type C arrow panels are intended to be used on high-speed, high-volume motor vehicle traffic control projects.
- Type D arrow panels are intended for use on authorized vehicles.

Type B and C panels are used by ODOT in temporary work zones (mobile or static) where work is taking place on the shoulder, or alongside the shoulder off the roadway. Type B and C panels can display a variety of modes including a caution mode. The caution mode displays are used to warn drivers that they are approaching a temporary work zone, *but not to change lanes*. Caution modes are used when work is taking place away from the travel lanes, either on the shoulder, or adjacent to the roadway. There are two caution mode configurations that are currently used to display an advance warning to motorists. These two displays are:

1. A "flashing line" display:

First Sequence **Second Sequence**

2. A "flashing four-corner" display:

First Sequence **Second Sequence**


Prior to the 2000 version of the MUTCD, the "*flashing line*" and the "*flashing four-corner*" displays were allowed as an advance warning for shoulder work, blocking the shoulder, and for roadside work near the shoulder.

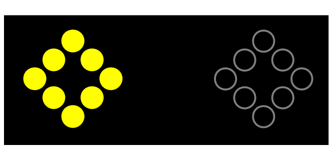
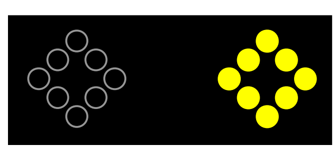
The 1988 edition of the MUTCD did not specify a configuration for the caution mode, other than stating: "The caution mode consists of four or more lamps, arranged in a pattern which will not indicate a direction." Part VI of this edition was reissued as Revision 3 of the 1988 MUTCD and included the flashing corner display. An errata to Revision 3 was then issued which added an additional caution mode of four or more lights in a horizontal direction.

Both of these displays were included for comments in Part 6 of the MUTCD 2000, but only the flashing four-corner display made it into the final version of the MUTCD 2000. However, the Federal Highway Administration (FHWA) has indicated that the flashing line display was inadvertently omitted from the 2000 edition of the MUTCD, and will be corrected through an errata to be published in the Federal Register *(Fortey 2001)*.

In the past, ODOT striping crews as well as District maintenance crews have used a third display mode in addition to the two types of displays noted above. The *"sequentially flashing diamond"* display, shown below, has been used by ODOT in both stationary work zones and slow moving operations such as striping and sweeping.

3. A "sequentially flashing diamond" display:

First Sequence **Second Sequence**

Since the sequentially flashing diamond mode was not prescribed in the MUTCD 2000, ODOT crews have discontinued its use. However, because of the diamond display's reliable performance in the past, there is wide support for its return as an advance warning device in temporary (static or slow moving) work zones. Consequently, ODOT decided to evaluate the three display modes to determine which is the most effective in providing advance warning to motorists.

Prior to starting the study, a request was made to FHWA to use non-MUTCD compliant caution modes in this research project. FHWA subsequently granted permission to test and evaluate all three displays.

1.2 OBJECTIVES AND RESEARCH METHODOLOGY

The overall objective of this study was to evaluate the effectiveness of the sequentially flashing diamond mode as an advance warning device by comparing it to the two other flashing modes (line, and four-corner). The research would provide maintenance managers and crews information on which flashing mode is the most effective warning device to use when working on the shoulder or alongside the roadway in stationary or slow moving work zones.

The following tasks were undertaken in order to accomplish the research objectives:

1. A literature search to determine the extent and applicability of previous research pertaining to arrow panel displays.
2. A survey of other state Departments of Transportation (DOT) to find out about their usage of arrow panel displays in temporary work zones.
3. A series of field tests of the three flashing modes in temporary work zones. The effectiveness of each mode was assessed at two locations, one on a two-lane highway and the other on a multi-lane highway.
4. A survey of motorists to obtain their perceptions about each display mode.

For brevity, in the remainder of the report, the use of "flashing" and "sequentially flashing" will be omitted when discussing ODOT's experience with the three display modes. In the balance of this report, the display modes will be referred to, as simply: "line", "four-corner" and "diamond."

2.0 LITERATURE REVIEW

Previous documented research on arrow panel displays is limited. Knapp and Pain *(1979)* investigated driver responses to different arrow panel displays. They tested various flashing and sequentially flashing displays including the arrow, double arrow and chevron, and two caution modes, the four-corner and line. The line display used in their study consisted of five lights illuminated along a horizontal axis in the center of the panel. The researchers conducted a survey using a series of nine film clips showing flashing and sequential arrows, flashing and sequential chevrons, a flashing double arrow, and the two caution displays. Each film clip depicted a different display mode in combination with placement in the travel lane or on the shoulder. The 20 people participating in the survey were shown the same series of nine film clips twice. After each clip, they were asked to select one of four responses which referred to an action they, as a driver, should take when seeing the display. When the caution modes (four-corner and the partial line) were shown, more than half of the participants misinterpreted their meaning. As a result, the authors recommended that the caution display "be evaluated as a separate entity to determine optimum caution configuration and whether, in fact, the arrow board is appropriate for this message at all" *(Knapp and Pain 1979)*.

Bryden *(1979)* evaluated the effectiveness of flashing arrow panels for slow moving maintenance operations. He investigated the use of the sequential stem arrow mode on two sizes of arrow boards [*panels*]. A smaller size board with a sequential chevron display was also evaluated. These display modes were intended to inform upstream motorists to change lanes because of striping operations in the occupied lane. Bryden found that the sequential stem arrow mode appeared to provide clearer directional indication to approaching traffic when used on the largest arrow board. Approaching traffic shifted out of the occupied lane sooner when the larger board was utilized.

A study by Mace and others *(1996)* looked at photometric requirements for arrow panel visibility. They conducted laboratory and field studies to identify the minimum lamp intensity needed for legibility of arrows and chevrons on Type C arrow panels.

Currently, the Utah Department of Transportation (UDOT) is conducting research to compare the effectiveness of the "flashing diamond" with the MUTCD 2000 recommended "flashing caution" mode of the arrow panel. Their research consists of two parts: (1) a comprehension/recognition study, and (2) a field study. In the comprehension/recognition study, various work zone situations with flashing diamond and flashing caution warning signs will be videotaped. The videotapes will be shown to people, who will be tested for their comprehension and recognition of the displays. In the field study, work zones will be randomly selected and data on performance measures (speed reduction, lane migration, and conflict percentage) will be collected and analyzed using statistical testing. UDOT's study is in progress with results expected by January 02 *(UDOT 00)*. It is anticipated that Utah's research findings will complement the results of ODOT's research.

3.0 SURVEY OF OTHER STATES

Other state DOTs were surveyed using an internet-based questionnaire to obtain information about their use of arrow panel displays. The arrow panel related questions asked on the survey are included in Appendix A. Completed surveys were e-mailed back to ODOT's Research Group. A total of 33 states responded, and 27 indicated they use arrow panel displays for static work zones and for slow moving operations.

Figure 3.1 shows the distribution of arrow panel displays which are being used by state DOTs for slow moving operations. The total does not sum to 27 because some states indicated that they use more than one display mode. The four-corner and line displays are the most widely used modes. A small percentage of the respondents indicated they have used the diamond display.

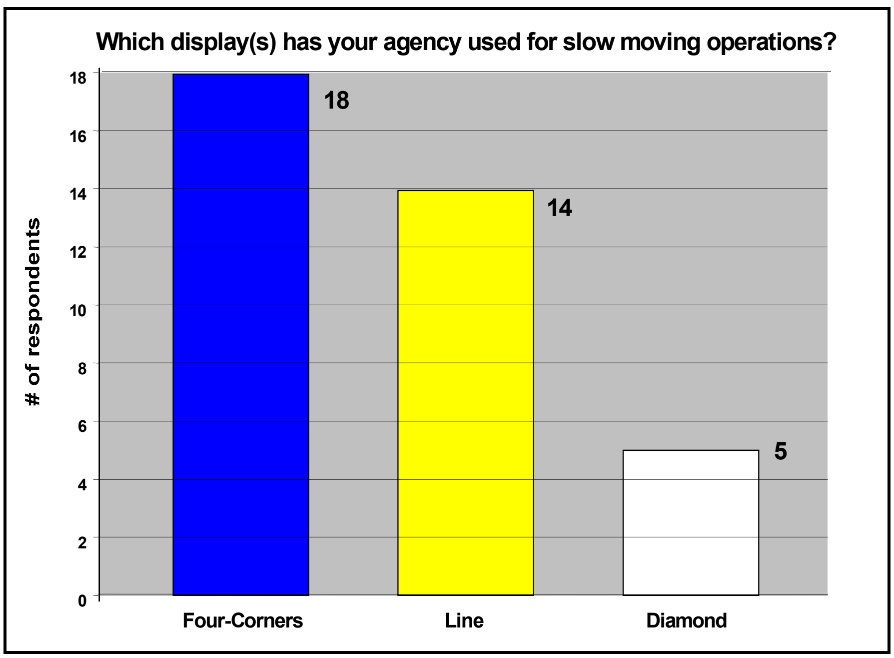


Figure 3.1: Type of Arrow Display Mode Used for Slow Moving Operations

The survey also asked state DOTs if they are using arrow panel displays for static operations. The distribution of responses, shown in Figure 3.2, is about the same as for slow moving operations.

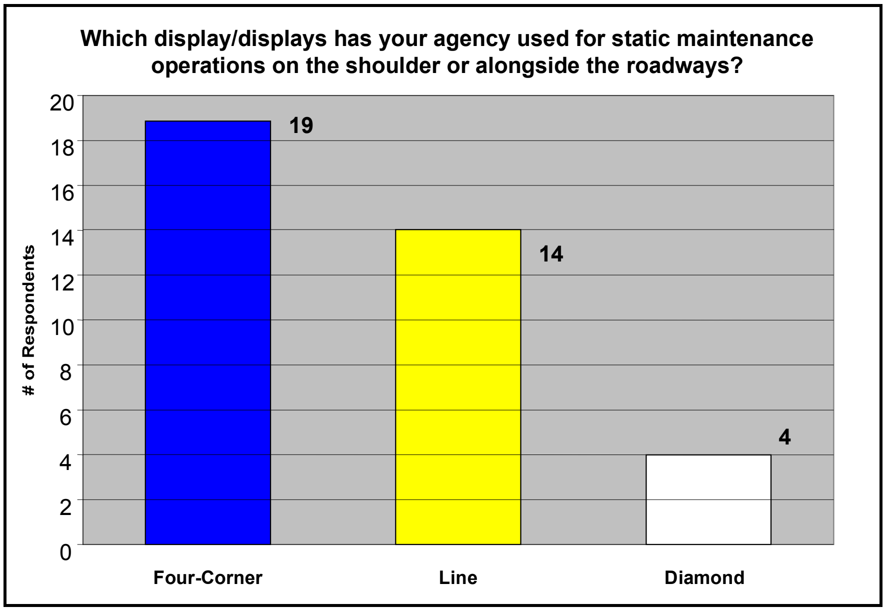


Figure 3.2: Type of Arrow Display Mode Used for Static Operations

State DOTs were also asked to describe the types of work being done when the arrow panel displays were used. The answers were very uniform. The most widespread answers included:

- Striping;
- Sweeping;
- Shoulder work;
- Guardrail replacement;
- Landscape maintenance;
- Ditch cleaning;
- Cleaning up right of way; and
- Mowing.

States were asked to rate the effectiveness of each of the three display modes they have used, on a scale of 1-5. A rating of "1" represents "not effective" and "5" is "highly effective." Most agencies only rated the display modes they were currently using. One of the possible answers was also "no opinion." The majority of the "no opinion" answers were for the diamond display. Figure 3.3 shows the distribution of the responses.

The average values of the effectiveness ratings for each display mode are provided in Table 3.1.

Table 3.1: Average and Standard Deviation for Effectiveness Ratings

Display Mode	Number of Responses	Average Score	Standard Deviation
Four-Corner	21	3.19	0.93
Line	16	3.38	1.15
Diamond	6	3.50	1.05

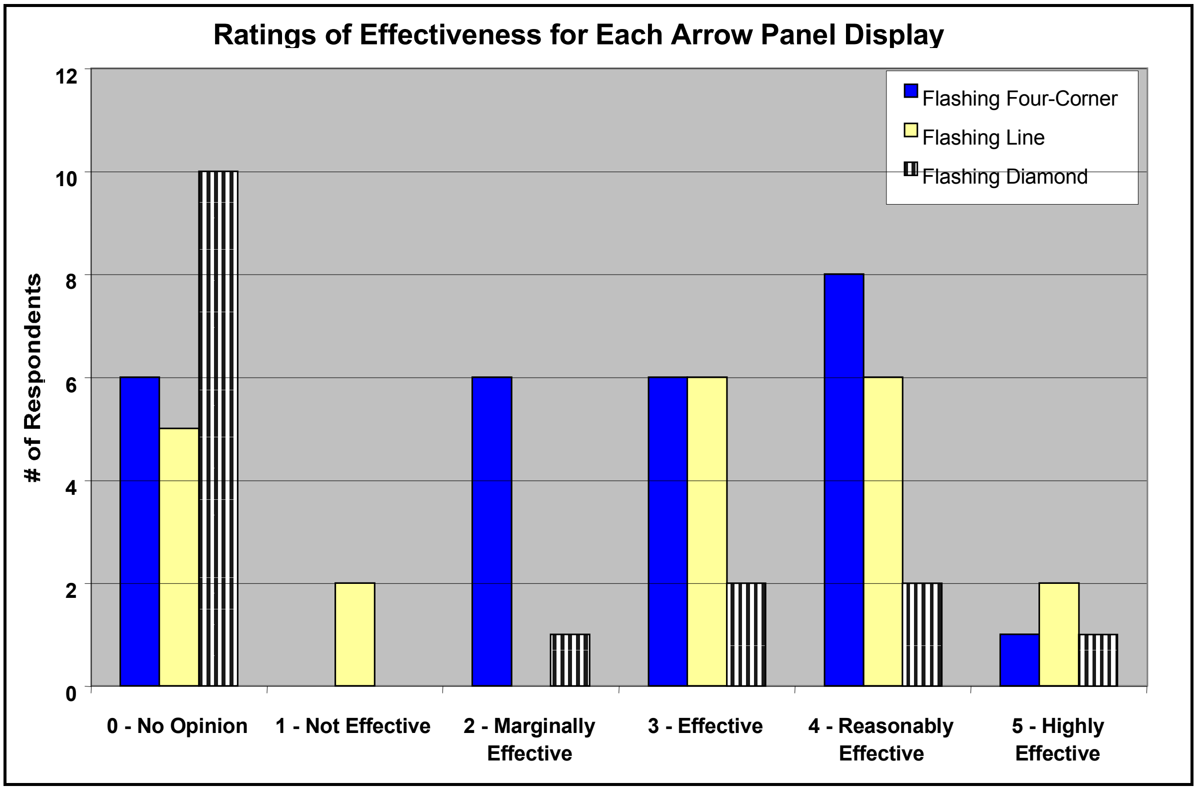


Figure 3.3: Effectiveness of Each Display Mode Used as an Advance Caution Warning to Drivers

Overall, the DOT survey showed a general satisfaction with the line and four-corner displays. As seen in Figure 3.3, the four-corner display was rated "effective" or higher by 15 states, while 6 rated the four-corner display "marginally effective." The line display received ratings "effective" or higher from 14 states. Alternatively, 2 states gave "not effective" ratings for the line display. The average rating for the line display is slightly higher than the four-corner display.

The ratings for the diamond resulted in the highest average score. The diamond received "effective" or higher ratings from 5 of 6 states. Yet, it is difficult to draw comparisons with the others because of the limited number that were rated.

The DOT survey generated some interesting results, but the display mode ratings did not point to a clear standout among others. Thus, the importance of ODOT's research effort was even further advanced. As noted earlier in Section 1.2, the research effort included field trials in which three arrow panel display modes were tested in temporary work zones. The next chapter describes in greater detail the data collection and results associated with the field trials.

4.0 FIELD TRIALS

4.1 EXPERIMENT DESIGN AND DATA COLLECTION PROCEDURE

Field trials were conducted at two locations in May 2001. The first was on OR Route 22, a multi-lane highway, 5 miles (8 km) west of Salem. At this location, there are two lanes in each direction, with a continuous two-way left turn lane in the median. The shoulders are paved and 3.7 m wide on each side of the highway. The speed limit is 55 mph (88 kph) and average daily traffic is 27,900.

The other test section was located 6 miles (9.6 km) south of Monmouth on OR Route 99W. Here, the highway is two lanes (one in each direction), with 3.0 m paved shoulders along each travel lane. The speed limit is 55 mph and average daily traffic is 7,900.

These two locations were chosen because at each of the sites, ODOT's Research Group had been operating traffic recorders to collect speed data for another study. A Peek Traffic "TrafiCOMP® III, Model 241 Recorder" was operating at the OR 99W site, and a Peek Traffic "Automatic Data Recorder" (ADR) was in place at the OR Route 22 site. Each of the two recorders was configured to count vehicles and record their speed. The speed data was collected for each hour and stored in 10 speed bins. The bins set up for each recorder included:

- 0 - 40 mph
- 40+ - 45 mph
- 45+ - 50 mph
- 50+ - 55 mph
- 55+ - 60 mph
- 60+ - 65 mph
- 65+ - 70 mph
- 70+ - 75 mph
- 75+ - 80 mph
- 80+ - 150 mph

The bins were set up in increments of 5 mph except for the first and last bins. The first bin stores all vehicle speeds from 0 - 40 mph traveling in a particular hour. For instance, if a vehicle is traveling at 38 mph, it will be counted and stored in the 0 - 40 mph bin as one vehicle traveling between 0 and 40 mph. If a vehicle is traveling just over 55 mph, it will be stored in the next higher bin, i.e., 55+ - 60 mph.

Prior to the field trials, traffic volume and speed data had been collected at each site for a 30-day period to establish a baseline condition.

The field trials at each of the two sites took place on consecutive days, May 15 (OR Route 22), and May 16, 2001 (OR Route 99W). The total evaluation time at each site was nine hours, divided into three, 3-hour test periods. Table 4.1 summarizes the schedule for field trials. To avoid confusion, military time is used here and in the remainder of the report to denote the hourly time intervals (9:00 A.M. is 0900, . . .1:00 p.m. is 1300, etc).

Table 4.1: Daily Schedule for Arrow Panel Display Field Trials

Time Interval for Each Arrow Panel Display Mode	Time Period
0900 to 1000	Morning
1000 to 1100	Morning
1100 to 1200	Morning
1200 to 1300	Afternoon
1300 to 1400	Afternoon
1400 to 1500	Afternoon
2100 to 2200	Night
2200 to 2300	Night
2300 to 2400	Night

The tests at each site involved setting up a temporary work zone in the shoulder. The work zone consisted of two ODOT ¾-ton trucks parked on the shoulder, along with appropriate signing and coning. The rear vehicle was parked approximately 10 m (33 ft) downstream from the speed recorder. A "Type B" arrow panel (Figure 4.1) was mounted on the rear vehicle.

Figure 4.1: Type B Arrow Panel Display Mounted on ¾-ton Truck

In both test sites, the lead, "working" vehicle was positioned 170 m (186 yd) downstream from the arrow panel. Two advance warning signs were placed 170 m apart upstream from the arrow panel vehicle. The layout of the work zones at each test site is depicted in Figures 4.2 and 4.3.

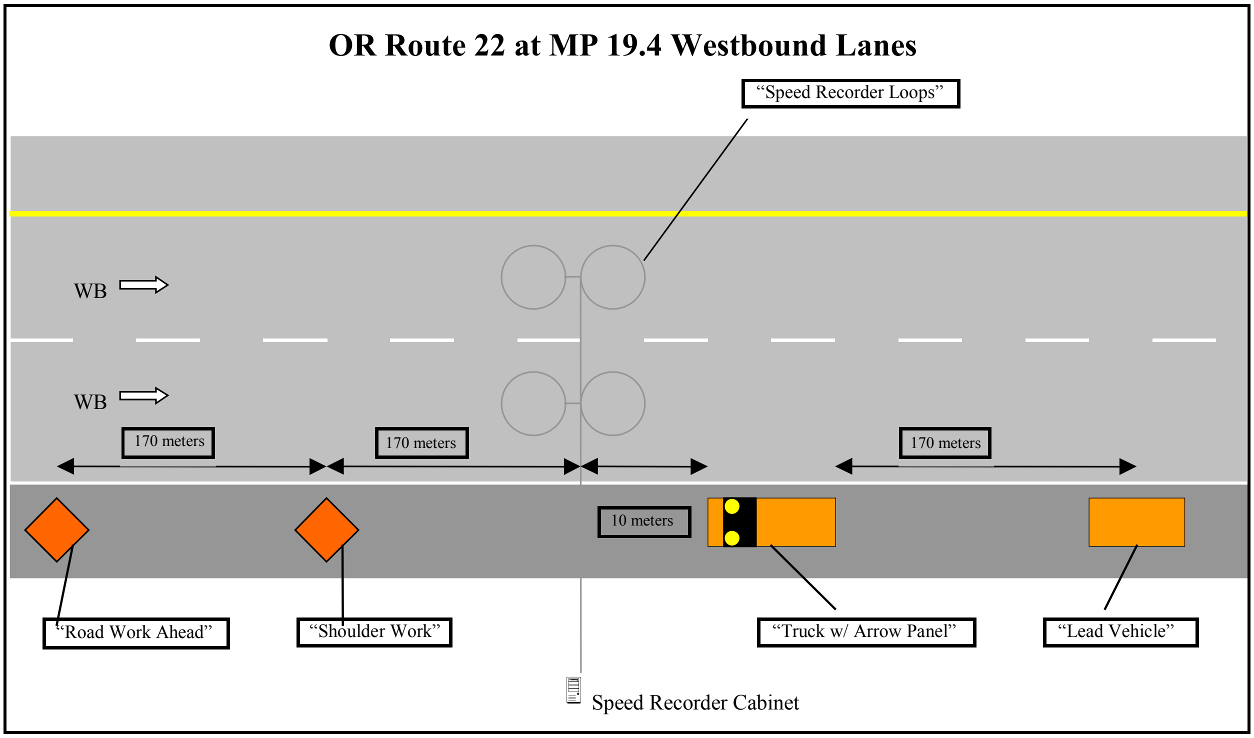


Figure 4.2: Temporary Work Zone Layout on OR Route 22

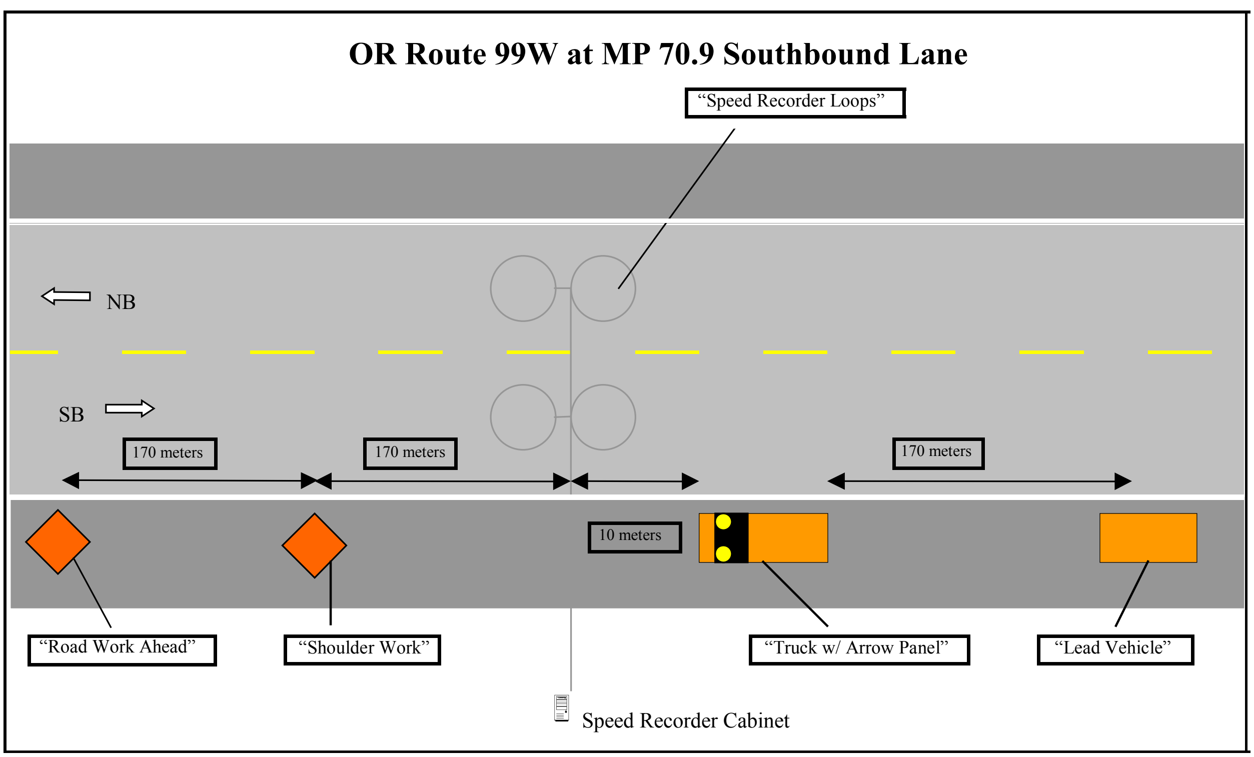


Figure 4.3: Temporary Work Zone Layout on OR Route 99W

No tests were done during morning and afternoon peak traffic hours, in order to eliminate the effects of congestion. The nighttime period started at 2100 (9:00 P.M.) because sunset occured at 2035 (8:35 P.M.). For every 3-hour period, each of the modes was displayed continuously in one-hour increments. Traffic volume and speed data were collected for each hour.

During field trials, observers from ODOT's Research Group were present for the entire eighteen hours of testing. They observed vehicle movements and ensured the arrow panel displays were changed at the beginning of each hour. Because of limited pull-off space adjacent to the roadway at both test sites, the observers were positioned about 120 m in advance of the arrow panel display. Any braking or lane shifts more than 120 m upstream of the arrow panel could not be observed, but within 120 m, the researchers documented:

- Brake light use (counts);
- Near-conflicts (counts of lane changes or other actions which require braking or evasive action from other vehicles); and
- Lane changes (on OR Route 22) and where they occur in reference to the arrow panel.

Data on these characteristics are not included in this report because their occurrences were extremely low, and no pattern was demonstrated. For instance, on the OR Route 22 site, brake light usage ranged from 1 to 20 incidences during each hour of observation. The highest rate of usage was 47 per 1,000 vehicles, which occurred late at night. Only one near-conflict was recorded at each site, and the conflicts could not be attributed to the presence of the arrow panel display. The number of lane changes observed at the OR Route 22 site was also very low. For these reasons, it was decided not to incorporate observational data on brake light usage, lane changes, and near conflicts into the report. The data is available from ODOT's Research Group.

4.2 OR ROUTE 22 FIELD TRIALS

Field trials at the OR Route 22 test location began at 0900 after the temporary work zone was set up on the westbound shoulder, and the arrow panel display was activated. The diamond display was used during the first hour, followed by the line display during the next hour. The four-corner was used in the third hour of the morning period. At 1200 the cycle was repeated; starting with the diamond, followed by the line display, and ending with the four-corner. For the nighttime period beginning at 2100, the order was changed. The line display was used in the first hour, followed by the four-corner, and then the diamond in the last hour.

During the nine hours of testing, traffic volume data and speeds were recorded with the Peek ADR. The following statistics were determined for each hour:

- Lane Distribution (percentage of vehicles in each lane);
- Average Speed; and
- 85th Percentile Speed.

In sections 4.2.1 through 4.2.5, the results of the data collection efforts are presented.

4.2.1 Lane Distribution

Lane distribution is important because it indicates how many vehicles are moving away from the temporary work zone set up on the shoulder. As more vehicles shift to the inside (left) travel lane, potential conflicts between work vehicles, workers and motorists are reduced, which creates a safer environment for the workers and traveling public.

4.2.1.1 Results

Hourly vehicle counts were recorded for each travel lane during the 30-day baseline period and for each hour during the nine hours of testing. Table 4.2 provides a summary of lane distribution (percent in each travel lane) for the 30-day baseline period and the nine-hour test day. In addition, the test day hourly traffic volumes combined for the two westbound lanes are also provided in Table 4.2. On the test day, the traffic volumes were highest during the afternoon period (775-880 vehicles per hour). Lower traffic volumes were experienced at night. During the nighttime period, traffic decreased from 419 vehicles per hour between 2100-2200, to 192 in the last hour.

For every hour during the baseline period, the percentage of vehicles traveling in the right lane (the lane adjacent to the shoulder) was much higher than the left lane, ranging from 58.7 to 71.1%. During the nine-hour test period, the reverse pattern occurred; more vehicles traveled in the left lane than in the right lane. During the two daytime test periods, 58.9 to 61.8% of traffic were in the left lane. At night, the effect was even greater. The hourly distributions of vehicles in the left lane during the nighttime hours ranged from 88.7 to 92.7%.

Table 4.2: Arrow Panel Display Field Test – OR Route 22 – 5/15/01 – Lane Distribution

Time	Display	Test Day Volume (WB Lanes)	% of Vehicles in Right Lane		% of Vehicles in Left Lane		Percentage Point Difference in Left Lane
			Test Day	30-Day Baseline	Test Day	30-Day Baseline	
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8) = (6) - (7)*
0900 to 1000	Diamond	653	38.3%	63.5%	61.7%	36.5%	**25.3**
1000 to 1100	Line	708	40.5%	62.7%	59.5%	37.3%	**22.2**
1100 to 1200	4-Corner	704	41.1%	61.6%	58.9%	38.4%	**20.6**
1200 to 1300	Diamond	880	38.2%	59.9%	61.8%	40.1%	**21.7**
1300 to 1400	Line	775	40.5%	59.2%	59.5%	40.8%	**18.7**
1400 to 1500	4-Corner	882	40.7%	58.7%	59.3%	41.3%	**17.9**
2100 to 2200	Line	419	11.9%	65.3%	88.1%	34.7%	**53.3**
2200 to 2300	4-Corner	293	11.9%	69.4%	88.1%	30.6%	**57.4**
2300 to 2400	Diamond	192	7.3%	71.1%	92.7%	28.9%	**63.8**

4.2.1.2 Statistical Testing

To examine the statistical relationship between type of arrow panel display mode and lane distribution, a chi-square test for independence was performed using the test day lane distributions for each of the 3-hour periods. A chi-square test for independence is a statistical test used to determine whether or not there is a relationship between two variables; in this case, (1) arrow panel display mode and (2) lane distribution. When two variables are independent, the distribution for one variable will not depend on the categories of the second variable. Thus, if the variables are independent, the distribution of vehicles in each lane for one arrow panel display type will have comparatively the same proportions as the other two display modes.

The chi-square statistic (χ^2) is computed for the actual lane distribution data (for each of the three, 3-hour periods) shown in Table 4.3. It is then compared with a theoretical value of chi-square that is obtained from statistical tables. The chi-square test uses the actual traffic volumes recorded for the left and right lanes contained in Table 4.3.

Table 4.3: Lane Distribution Table for Chi-square Testing

Time	Time Period	Display	Test Day Volume Left Lane	Test Day Volume Right Lane	Test Day Volume (Both Lanes)
0900 to 1000	Morning	Diamond	403	250	653
1000 to 1100	Morning	Line	421	287	708
1100 to 1200	Morning	4-Corner	415	289	704
Morning Total			1,239	826	2,065
1200 to 1300	Afternoon	Diamond	544	336	880
1300 to 1400	Afternoon	Line	461	314	775
1400 to 1500	Afternoon	4-Corner	523	359	882
Afternoon Total			1,528	1,009	2,537
2100 to 2200	Night	Line	369	50	419
2200 to 2300	Night	4-Corner	258	35	293
2300 to 2400	Night	Diamond	178	14	192
Night Total			805	99	904

The chi-square statistic is calculated using the following formula:

$$\chi^2 = \sum \frac{(O_j - E_j)^2}{E_j} \tag{4.1}$$

O_j is an observed cell frequency in Table 4.3. The table cell entries are the traffic volumes in each of the two lanes (left and right) for each period. For instance, the observed frequencies for the morning period, taken from Table 4.3, are shown below in the grayed portion of Table 4.3a.

Table 4.3a: Lane Distribution Table in the Morning Period Used for Chi-square Testing

Display	Left Lane Volume	Right Lane Volume	Total Volume (Both Lanes)
Diamond	403	250	653
Line	421	287	708
4-Corner	415	289	704
Total	1,239	826	2,065

E_j is an expected cell frequency. Expected frequencies represent the frequencies one would expect to occur based on the assumption that no relationship exists between arrow panel display mode and lane distribution. This means that proportionately, the lane distribution for each arrow panel display will be the same as in the total. Thus, using the data contained in the "Total" row in Table 4.3a, the proportion used is:

- Percent vehicles in left lane: 1,239/2,065 = 60%
- Percent vehicles in right lane: 826/2,065 = 40%

There is a formula that can determine the expected frequency corresponding to each of the six table cells that will result in the same proportion as the "Total" row in Table 4.3a. The formula which uses corresponding row and column totals (like those shown in Table 4.3a) to calculate each cell expected frequency is:

$$\mathbf{E_j = [(Column\ Total)(Row\ Total)]/Grand\ Total} \qquad (4.2)$$

As an example, to calculate the expected cell frequency for the diamond display/left lane cell, the row total is 1,239. The column total is 653, and the grand total is 2,065. Using Equation 4.2, the expected cell frequency would be computed as follows:

$$E = [(1{,}239)(653)/2{,}065] = 391.8$$

When this calculation is performed for each of the cell frequencies, the expected lane distribution is shown in Table 4.3b. Note that each row in Table 4.3b has the same proportions of vehicles in the left and right lanes.

Table 4.3b: Expected Lane Distribution Table in the Morning Period Used for Chi-square Testing

Display	Left Lane Volume	Right Lane Volume	Total Volume (Both Lanes)
Diamond	391.8 (60%)	261.2(40%)	653 (100%)
Line	424.8 (60%)	283.2 (40%)	708 (100%)
4-Corner	422.4 (60%)	281.6 (40%)	704 (100%)
Total	1239 (60%)	826 (40%)	2,065 (100%)

The chi-square statistic can now be calculated for each three-hour period using Equation 4.1. The chi-square square statistic is then compared to the value of the theoretical chi-square. The theoretical value of chi-square is determined using degrees of freedom associated with the three-hour period's lane distribution table (Table 4.3a) and the assumed significance level (α).

Degrees of freedom are calculated by multiplying one less then the number of rows in the lane distribution table times one less than the number of columns in the table. In Table 4.3a, there are three rows that represent a lane distribution for one of the three displays. There are 2 columns, each representing one of the two travel lanes. The degrees of freedom are:

$$(3-1) * (2-1) = 2 \text{ degrees of freedom.}$$

The assumed significance level (α) is 0.05, which represents the probability of error that is accepted in making an inference that a statistical relationship exists between arrow panel display type and lane distribution. A 5% significance level is conventionally used in physical and social science research, including speed-related studies such as this one.

If the chi-square statistic (χ^2) is greater than the theoretical value of chi-square, in can be inferred (with a 0.05 probability of error) that a statistical relationship does exist. The results of the chi-square test for each three-hour period are presented in Table 4.4.

Table 4.4: Results of Chi-square Testing for OR Route 22 Lane Distribution

Period	Chi-square (χ^2)	Theoretical Chi-square	Statistical Relationship?
Morning	1.21	5.99	No
Afternoon	1.59	5.99	No
Night	3.35	5.99	No

In all three periods, the observed chi-square value is less than the theoretical chi-square value, which means there is no apparent statistical relationship between arrow panel display mode and lane distribution. Thus, during the test day, the chi-square tests show that lane distribution is not dependent on arrow panel display type.

It should be noted that even though there is no apparent statistical relationship between arrow panel display mode and lane distribution, the data set covers only one test day. Repeated trials using the arrow panel display modes over a greater number of days could produce a different result. In addition, although the test day statistical analysis showed no relationship, one can infer this result also means that all three displays performed equally in producing a vehicle shift from the right to left lane.

Further, the chi-square test only used test day data and does not take into account the baseline lane distributions and the changes between baseline and test day. In looking at the percentage point differences between the baseline and test condition for each hour in Table 4.2, differences ranged from 17.9 to 63.8 percentage points. During the nighttime three-hour period, the highest percentage difference occurred when the diamond display was operating. Between 2300-2400, 92.7% of the vehicles traveled in the left lane, which was 63.8 percentage points higher than baseline. For the morning and afternoon periods, the highest percentage point differences also occurred when the diamond display was operating (between 0900-1000 and 1200-1300).

4.2.2 Speed Data

4.2.2.1 Average Speeds

Average speeds were calculated from the frequency distributions of the binned speed data. The binned speed data for each of the two westbound lanes were combined into one frequency distribution. Figure 4.4 shows the calculated average hourly speeds in the westbound lanes for the test day and the average hourly speeds calculated for the 30-day baseline period.

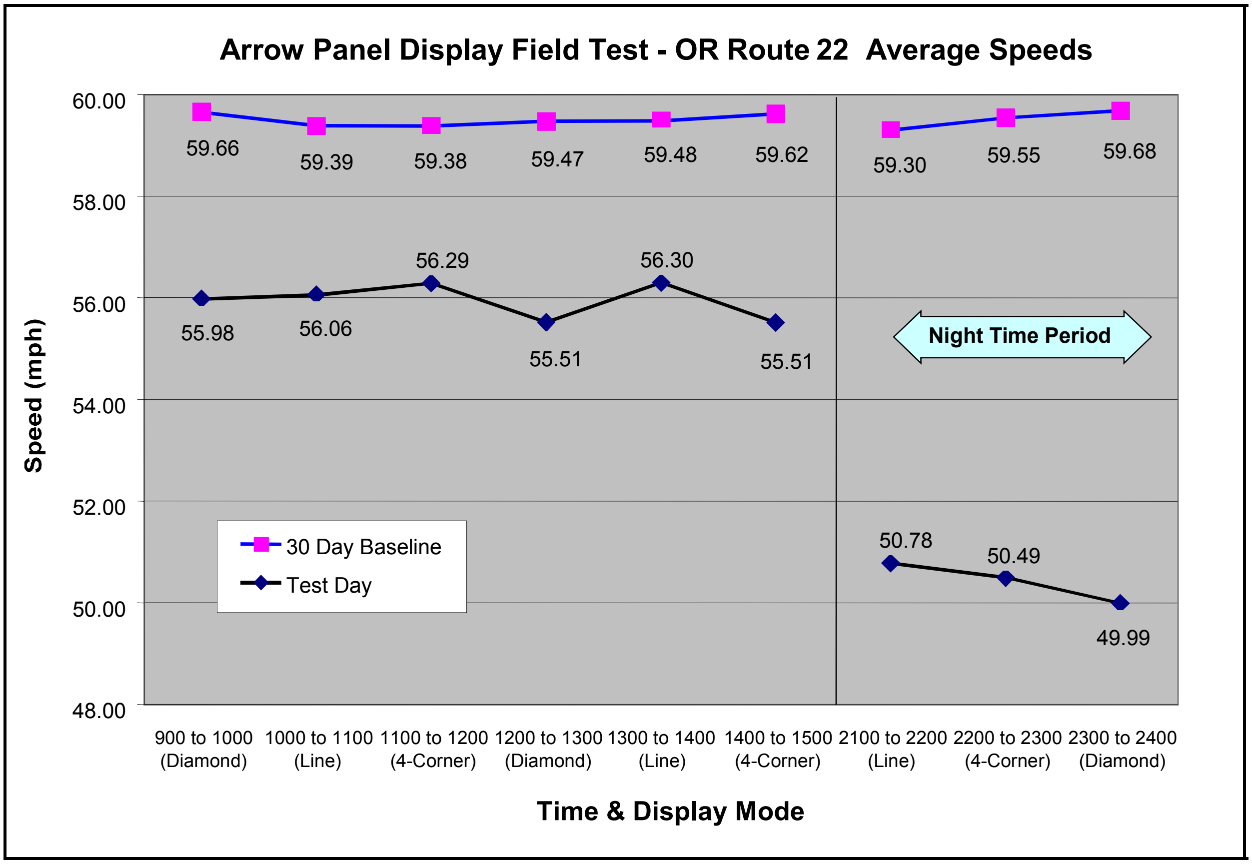


Figure 4.4: Average Speeds on OR Route 22

For each hour of the test day, average speeds were lower than the corresponding baseline hour. During the morning three-hour period, the reductions from baseline average speeds ranged from 3.09 to 3.68 mph. The greatest reduction occurred during 0900-1000 when the diamond display was used. In the afternoon three-hour period, baseline and test day speed differences ranged between 3.19 and 4.11 mph. The largest reduction took place when the four-corner display was operating between 1400-1500. Reductions in average speed between baseline and test day were much greater during the nighttime three-hour period, ranging from 8.52 to 9.70 mph. The largest reduction was observed in the last hour (2300-2400) when the diamond display was used.

4.2.2.2 85th Percentile Speeds

Figure 4.5 shows the 85th percentile speeds for the westbound lanes calculated for each hour during the test period. As noted earlier, the binned speed data for each of the two westbound lanes were combined into one frequency distribution, which was used to calculate an 85th percentile speed for each hour. At the 85th percentile speed, 85% of the vehicles in a particular hour are traveling at lower speeds. The remaining 15% are exceeding the 85th percentile speed.

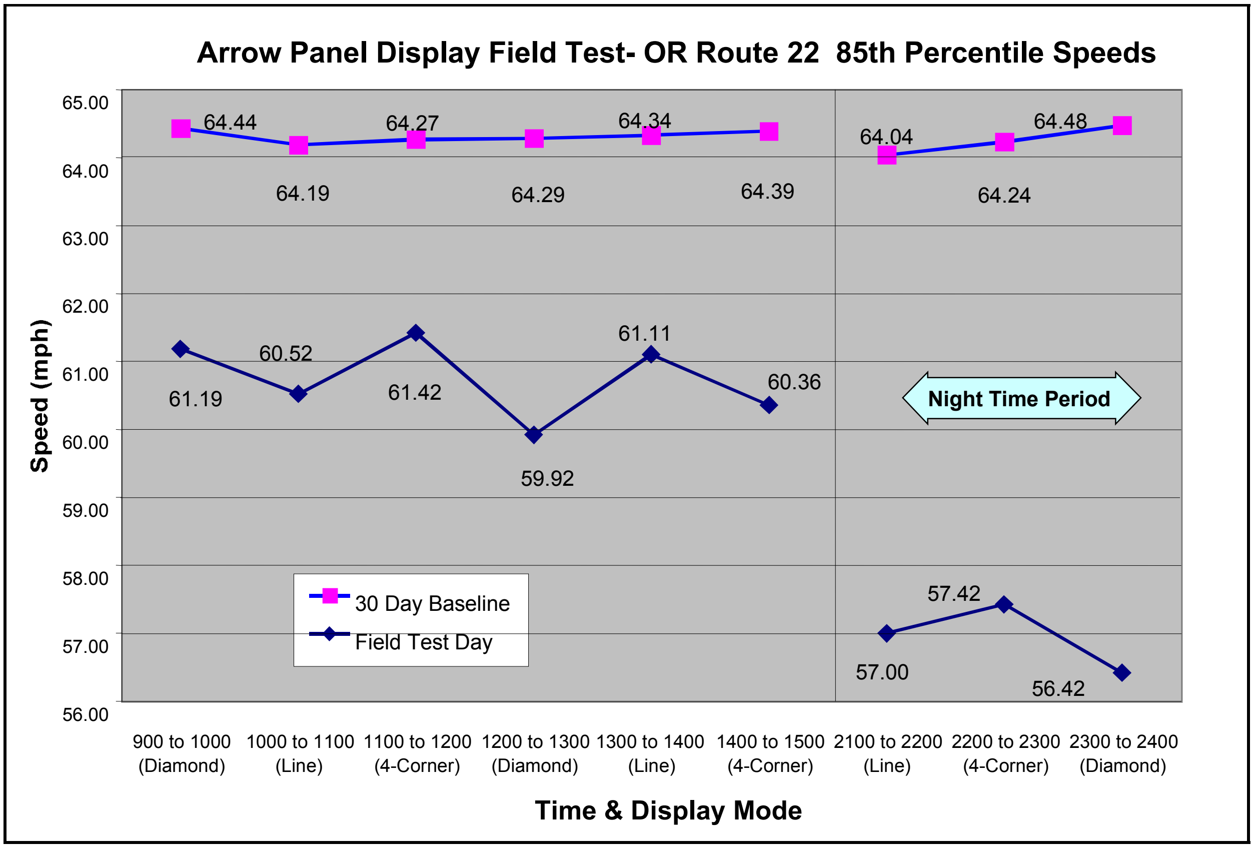


Figure 4.5: 85th Percentile Speeds on OR Route 22

The 85th percentile speeds exhibit a similar pattern as the average speeds. During the morning and afternoon periods, test day 85th percentile speeds for each hour were between 4 and 7% lower than the corresponding baseline hour. In the morning period, the greatest reduction (64.19 to 60.52 mph) occurred between 1000-1100 when the line display was used. In the afternoon period, the greatest difference between test day and baseline (64.29 to 59.92 mph) took place between 1300 and 1400 when the diamond display was operating. At night, the reductions were much higher, and again, the greatest difference in test day and baseline 85th percentile speeds occurred when diamond display was used between 2300-2400. The 85th percentile speed for this hour was reduced from 64.48 to 56.42 mph.

4.2.2.3 Statistical Testing

The binned speed data for each test day three-hour period are shown in Table 4.5. In the table, there are three rows for each three-hour period, each representing a speed distribution for one of the three displays. Each of the 10 columns represents one of the 10 speed bins. Because there are low numbers of vehicles in the upper speed bins, the four upper 10 speed bins were collapsed into one bin for statistical testing, the highest bin being 65+ mph. Table 4.5a contains the revised frequency distribution of speeds for each three-hour period.

Table 4.5: OR 22 Test Day Speed Distribution – Frequency Distribution for Counts of Vehicles Traveling at Speeds Within Each Bin Range

Time	Time Period	Display	Speed Bins										Total
			<40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80	>80	
0900 to 1000	Morning	Diamond	6	8	45	189	280	114	10	1	0	0	653
1000 to 1100	Morning	Line	2	8	42	222	317	103	12	1	0	1	708
1100 to 1200	Morning	4-Corner	3	8	49	194	308	128	9	4	1	0	704
Morning Total			11	24	136	605	905	345	31	6	1	1	2,065
1200 to 1300	Afternoon	Diamond	3	11	64	308	368	117	8	1	0	0	880
1300 to 1400	Afternoon	Line	5	7	39	222	357	130	13	2	0	0	775
1400 to 1500	Afternoon	4-Corner	10	18	66	275	372	121	17	2	1	0	882
Afternoon Total			18	36	169	805	1097	368	38	5	1	0	2,537
2100 to 2200	Night	Line	15	38	111	159	83	12	1	0	0	0	419
2200 to 2300	Night	4-Corner	15	27	82	95	62	12	0	0	0	0	293
2300 to 2400	Night	Diamond	9	24	50	70	36	3	0	0	0	0	192
Night Total			39	89	243	324	181	27	1	0	0	0	904

Table 4.5a: OR 22 Speed Frequency Distribution Table Used for Chi-square Testing

Time	Display	Speed Bins							
		<40	41-45	46-50	51-55	56-60	61-65	>65	Total
0900 to 1000	Diamond	6	8	45	189	280	114	11	653
1000 to 1100	Line	2	8	42	222	317	103	14	708
1100 to 1200	4-Corner	3	8	49	194	308	128	14	704
Morning Period Total		11	24	136	605	905	345	39	2,065
1200 to 1300	Diamond	3	11	64	308	368	117	9	880
1300 to 1400	Line	5	7	39	222	357	130	15	775
1400 to 1500	4-Corner	10	18	66	275	372	121	20	882
Afternoon Period Total		18	36	169	805	1097	368	44	2,537
2100 to 2200	Line	15	38	111	159	83	12	1	419
2200 to 2300	4-Corner	15	27	82	95	62	12	0	293
2300 to 2400	Diamond	9	24	50	70	36	3	0	192
Night Period Total		39	89	243	324	181	27	1	904

A chi-square test for independence was run to look at the effect of arrow panel display mode on speed during the test day. The chi-square test was used to determine whether or not there was a relationship between (1) arrow panel display mode and (2) speed. If the variables are independent, the frequency distribution of the binned speed data will not depend on the arrow panel display types. Thus, the distribution of speed data for one display will have comparatively the same proportions as the other two display modes.

The chi-square analysis was performed in the same manner as discussed previously in Section 4.2.1.2. The expected frequencies are calculated using Equation 4.2 and the column and row totals in Table 4.5a.

The chi-square statistic (χ^2) is computed using Equation 4.1 for each of the three time periods. The chi-square statistic is then compared with the theoretical value of chi-square determined from statistical tables using degrees of freedom associated with the speed distribution table (Table 4.5a.), and the assumed significance level (α). Table 4.5a contains three rows for each three-hour period, each representing a speed distribution for one of the three displays. There are seven speed bin columns. Thus, there are 12 degrees of freedom [(3-1) * (7-1)] associated with Table 4.5a.

The assumed significance level (α) is 0.05, representing the probability of error that is accepted in making an inference that a statistical relationship exists between arrow panel display type and speed. The results of the chi-square test are presented in Table 4.6.

Table 4.6: Results of Chi-square Testing for OR Route 22 Speed Distribution

Period	Chi-square (χ^2)	Theoretical Chi-square	Statistical Relationship?
Morning	8.92	21.02	No
Afternoon	28.13	21.02	Yes
Night	8.52	21.02	No

Based on the chi-square testing, there is no statistical relationship between display type and speed in the morning and nighttime periods. However, the afternoon period indicates a statistical relationship, as the calculated chi-square is greater than the theoretical value. During this period, the lowest average speeds (55.51 mph) were recorded when the diamond and four-corner displays were in use. The average speed during the hour when the line display was in use was almost 1 mph higher at 56.30 mph. Based on the results, it can be inferred that there is a relationship between type of arrow panel display and speed for the afternoon period.

So, why was there a statistical relationship in the afternoon period and not the other two, 3-hour periods? In looking at Table 4.5a, there were more vehicles in the afternoon period for the line display being recorded in the higher speed bins than for the four-corner and diamond displays. For example, in the 56-60 mph speed bin, there were 357 vehicles representing 46 % of the total distribution (775 vehicles). For the diamond, in the 56-60 mph speed bin, there were 368 vehicles recorded representing 42 % of the total (880). In the hour when the four-corner display was used, there were 372 vehicles recorded in the bin, representing 42 % of the total (882). Alternatively, in the morning and nighttime periods, the variation in speed bin totals was not as great as the afternoon period.

Although there was an apparent statistical relationship between arrow panel display mode and speed for the afternoon, and none for the morning and night time periods, it should be emphasized again that the data set covers only one test day. Repeated tests over a series of days could possibly result in a different outcome. Nonetheless, the field trial data for OR Route 22 yields interesting results. Recorded test day speed data certainly shows that all three displays were effective in achieving speed reductions.

4.3 OR ROUTE 99W FIELD TRIALS

Field trials at the OR Route 99W test location were conducted for the southbound lane. A temporary work zone was set up on the southbound shoulder and the arrow panel display was activated at 0900. The four-corner display was used during the first hour, followed by the line and then the diamond in the morning period. At 1200, the cycle was repeated for the afternoon period. For the nighttime period, the order was changed so that the diamond display was used in the first hour, followed by the line and then the four-corner display. During the nine hours of testing, traffic volume data and speeds were recorded for the southbound travel lane. The traffic volume and speed data were used to calculate average and 85th percentile speeds for each hour.

4.3.1 Speed Data

4.3.1.1 Average Speeds

Figure 4.6 shows average speeds for the southbound lane for the test day and 30-day baseline period. Average speeds were lower than the corresponding baseline hour, but the reductions were about twice that was exhibited at the OR 22 site. The most likely explanation can be attributed to the OR Route 99W site having only one travel lane in each direction. Unlike the OR Route 22 site, as traffic approached this work zone, vehicles could not move to an adjacent travel lane. Thus, there seemed to be a natural tendency for motorists to slow down. Also, the researchers observed during the testing that vehicles tended to brake more frequently as they traveled through the work zone.

As seen in Figure 4.6, average speed reductions in the morning three-hour period, varied from 7.57 to 8.89 mph. The greatest occurred between 1100-1200 when the diamond display was used. In the afternoon three-hour period, baseline and test day speed differences ranged between 6.68 and 7.67 mph. The greatest difference between baseline and test day also occurred when the diamond display was operating between 1400-1500. Again at night, the highest reduction (22.60 mph) took place when the diamond display was used (2100-2200).

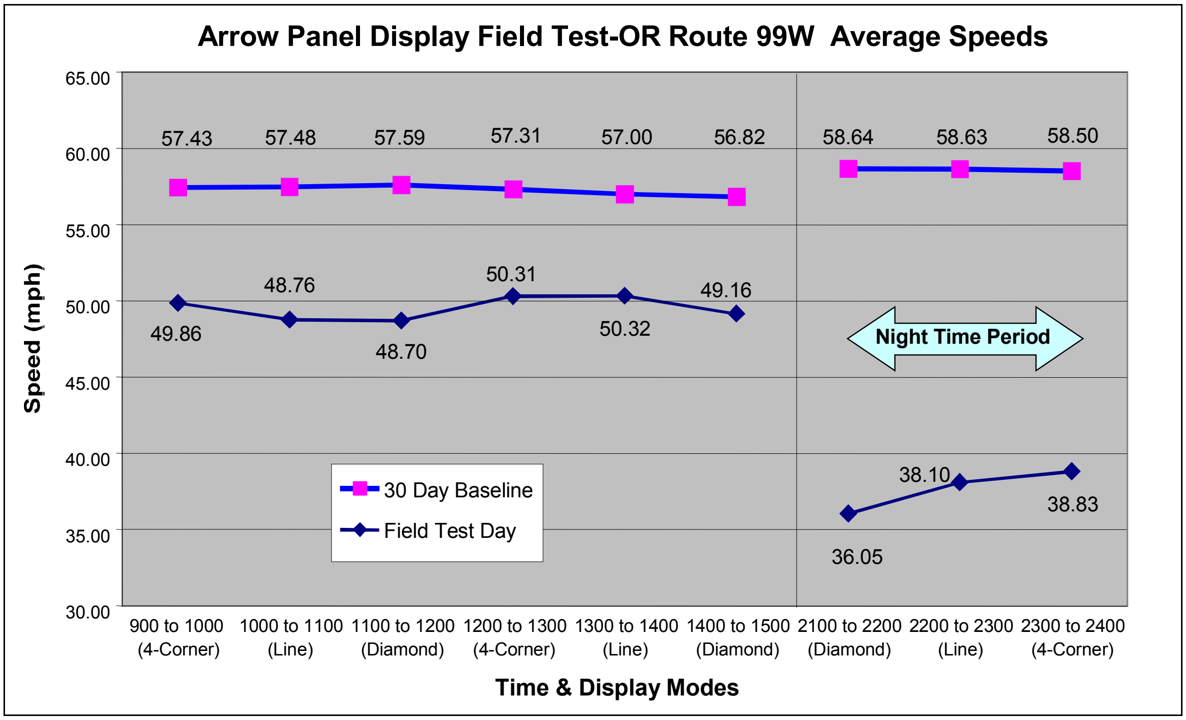


Figure 4.6: Average Speeds on OR Route 99W

4.3.1.2 85th Percentile Speed

Figure 4.7 shows the calculated hourly 85th percentile speeds for the southbound lane.

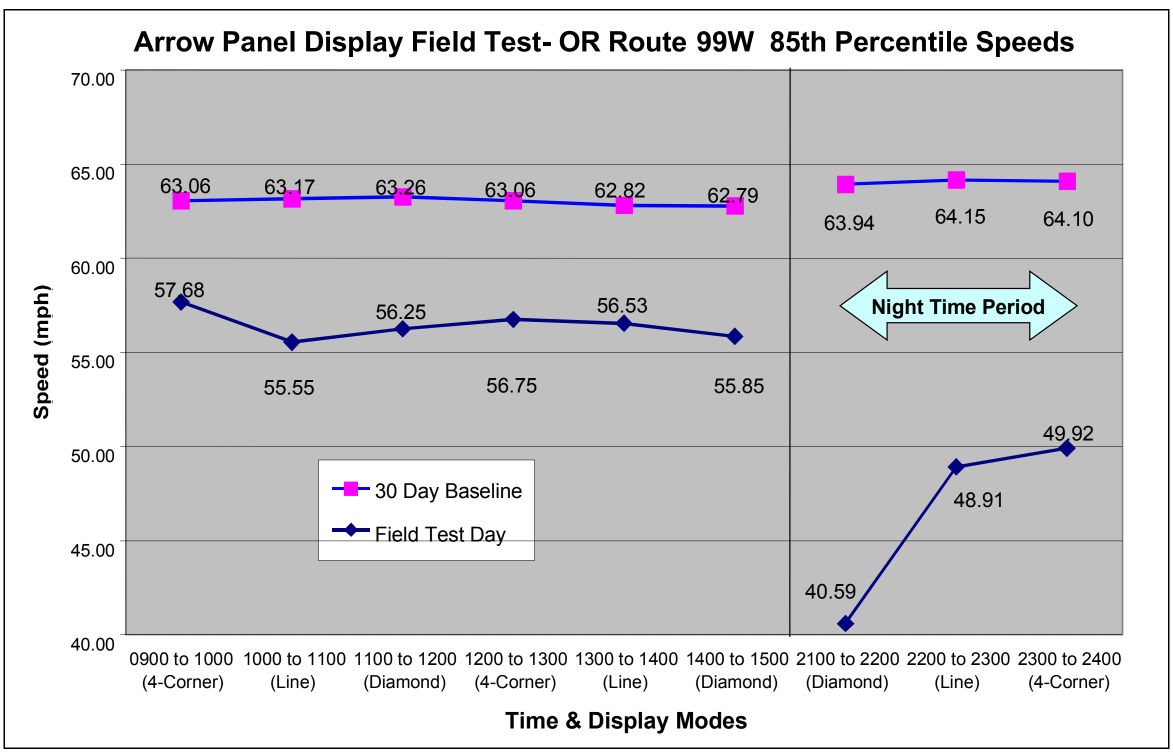


Figure 4.7: 85th Percentile Speeds on OR Route 99W

During the morning period, test day 85th percentile speeds were between 5.38 to 7.01 mph lower than the corresponding baseline hour, with the greatest reduction (63.26 to 56.25 mph) occurring between 1000-1100 when the line display was used. In the afternoon period, the speeds for each test day hour were between 6.39 to 6.94 mph lower than the baseline hour. The greatest reduction between test day and baseline (62.79 to 55.85 mph) occurred when the diamond display was operating. At night when the diamond display was used, the test day 85th percentile speed was 23.35 mph lower than baseline. When the line and four-corner displays were used, the reductions from baseline were 15.24 and 14.18 mph respectively.

4.3.1.3 Statistical Testing

A chi-square test was run to examine the effect of arrow panel display type on speed during the test day for each three-hour period. As noted in previous discussion, the chi-square test for independence examines whether or not there is a relationship between two variables; in this case, (1) arrow panel display mode and (2) speed. If the two variables are independent, the speed frequency distribution for one arrow panel display will have the same proportions as the other two display modes. The binned speed data for each test day 3-hour period is shown in Table 4.7.

For the morning and afternoon periods, the upper five speed bins were collapsed into one bin for the chi-square test because of low numbers of vehicles. As a result, six speed bins were used, with the upper bin being 60+ mph. For the nighttime period, because of even lower volumes and speeds, the upper seven bins were collapsed into one bin, 50+ mph. Table 4.7a contains the revised frequency distribution of speeds for each 3-hour period.

The chi-square analysis was performed in the same manner as discussed previously in Sections 4.2.1.2 and 4.2.2.3. The observed frequencies used to calculate the chi-square statistic are contained in Table 4.7a. The expected frequencies are calculated using Equation 4.2 and the column and row totals in Table 4.7a.

There are 10 degrees of freedom associated with the speed distribution table (Table 4.7a.) for the morning and afternoon. For the nighttime period, there are 6 degrees of freedom.

The assumed significance level (α) is 0.05. The results of the chi-square test are presented in Table 4.8.

The results of the chi-square testing show there is no statistical relationship between arrow panel type and speed for all three periods. Although there is no apparent statistical relationship, the results show that the three displays performed equally well during the test day trials. All were effective in reducing speeds.

Table 4.7: OR 99W Test Day Speed Distribution – Frequency Distribution for Counts of Vehicles Traveling at Speeds Within Each Bin Range

Time	Time Period	Display	Speed Bins										Total
			<40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80	>80	
0900 to 1000	Morning	4-Corner	13	22	64	51	31	13	2	0	0	0	196
1000 to 1100	Morning	Line	15	30	53	56	22	5	2	0	1	0	184
1100 to 1200	Morning	Diamond	16	40	52	59	29	8	1	0	0	0	205
Morning Total			44	92	169	166	82	26	5	0	1	0	585
1200 to 1300	Afternoon	4-Corner	6	26	65	60	25	10	2	0	0	1	195
1300 to 1400	Afternoon	Line	9	25	56	81	30	10	0	1	0	0	212
1400 to 1500	Afternoon	Diamond	14	28	79	58	27	8	1	0	0	1	216
Afternoon Total			29	79	200	199	82	28	3	1	0	2	623
2100 to 2200	Night	Diamond	59	23	11	5	0	0	0	0	0	0	98
2200 to 2300	Night	Line	45	18	14	8	2	0	0	0	0	0	87
2300 to 2400	Night	4-Corner	25	6	9	3	3	1	0	0	0	0	47
Night Total			129	47	34	16	5	1	0	0	0	0	232

Table 4.7a: OR 99W Speed Frequency Distribution Table Used for Chi-square Testing

Time	Display	Speed Bins						
		<40	41-45	46-50	51-55	56-60	>60	Total
0900 to 1000	4-Corner	13	22	64	51	31	15	196
1000 to 1100	Line	15	30	53	56	22	8	184
1100 to 1200	Diamond	16	40	52	59	29	9	205
Morning Period Total		44	92	169	166	82	32	585
1200 to 1300	4-Corner	6	26	65	60	25	13	195
1300 to 1400	Line	9	25	56	81	30	11	212
1400 to 1500	Diamond	14	28	79	58	27	10	216
Afternoon Period Total		29	79	200	199	82	34	623
Time	**Display**	**<40**	**41-45**	**46-50**	**>50**	**Total**		
2100 to 2200	Diamond	59	23	11	5	98		
2200 to 2300	Line	45	18	14	10	87		
2300 to 2400	4-Corner	25	6	9	7	47		
Night Period Total		129	47	34	22	232		

Table 4.8: Results of Chi-square Testing for OR Route 99W Speed Distribution

Period	Chi-square (χ^2)	Theoretical Chi-square	Statistical Relationship?
Morning	8.90	18.31	No
Afternoon	11.96	18.31	No
Night	7.83	12.59	No

4.4 DISCUSSION OF FIELD TRIAL DATA

The field trials demonstrated that vehicles reduced their speeds when the three displays were used. Chi-square testing for independence showed that there was no relationship between arrow panel display mode and lane distribution, or arrow panel display mode and speed, except for the afternoon period at the OR Route 22 site. With the absence of statistically significant differences, one can infer that all three displays achieved the same result in getting vehicles to either shift to an adjacent travel lane or travel slower through the work zone.

Further, when the baseline traffic data is considered in the analysis, there are differences in lane distribution and speed reduction among the three display types. In reviewing the test day and baseline data for each three-hour time period, the diamond display resulted in the greatest differences compared to the other two displays. Table 4.9 summarizes the data collection at the two sites, and shows for each three-hour period, which display resulted in the greatest difference between the test day and baseline conditions.

Table 4.9: Summary of Display Modes Resulting in the Greatest Difference from Baseline to Test Day

	OR Route 22			**OR Route 99W**	
Time Period	**Lane Distribution**	**Average Speed**	**85^{th} Percentile Speed**	**Average Speed**	**85^{th} Percentile Speed**
Morning	Diamond	Diamond	Line	Diamond	Line
Afternoon	Diamond	Four-corner	Diamond	Diamond	Diamond
Night	Diamond	Diamond	Diamond	Diamond	Diamond

When the diamond display was utilized on OR Route 22, the greatest differences in lane distribution between baseline and test day was experienced for all periods. The diamond display also resulted in greater reductions of average and 85^{th} percentile speed for two of the three, 3-hour time periods on OR Route 22. On the OR Route 99W site, reductions in average speed from baseline to test day were greatest when the diamond display was used for all three time periods. The greatest reductions in 85^{th} percentile speed were also achieved in the afternoon and night periods when the diamond display was operating.

As discussed previously, there are limitations in relying solely on two days of field trial data. Because of time and resource constraints, field trials were limited to two sites with testing at each lasting only nine hours. It would have been desirable to conduct multiple tests at each site over the course of several weeks, but the two days of field trials still yield compelling results. To further assess the effectiveness of each display, motorists were surveyed about arrow panel displays at an ODOT rest area. The survey results are presented in the next section.

5.0 MOTORIST SURVEY

5.1 METHODOLOGY

A survey of motorists was conducted at the Baldock Rest Areas on Interstate 5, approximately 15 miles (24 km) south of Portland. The survey was conducted by interviewers from the Oregon Department of Transportation and the University of Oregon Survey Research Laboratory from 12:00 noon to 10:00 P.M. on May 25, 2001.

At the rest areas, three ¾-ton trucks with type "B" arrow panel displays were staged together in one of the parking areas. Each vehicle's arrow panel displayed a different mode, so that the three displays (diamond, line and four-corner) operated simultaneously. Surveyors spent approximately five hours on the southbound rest area, and later in the day, the equipment and interviewers shifted to the northbound rest area to complete the surveys. At the end of the 10-hour survey period, 274 surveys had been completed.

Interviewers approached people after they were outside of their vehicles and asked if they would participate in a survey related to work zone safety. Those who agreed to participate were led to a point about 30 to 40 m in front of the three arrow panel displays, and then asked a series of questions about the displays.

5.2 RESULTS

The survey results presented here are in the general order in which the survey was given. The entire survey questionnaire is provided in Appendix B.

5.2.1 Question 1 – Meaning of the Displays

Three versions of the questionnaire were used. The versions differed only in the first question, where people were asked to look at one of the three flashing signs being displayed on the back of the truck. Approximately one-third of the people were asked to look at the four-corner display, another one-third were asked to look at the line display, and the remaining one-third were asked to look at the diamond display. Motorists were then asked: "Imagine that you are driving down the highway, and you see this flashing sign (*either the diamond, line or four-corner*). What would you do if you saw this flashing sign?"

Table 5.1 summarizes the answers. More than 70% of the respondents for all three displays indicated they would slow down, reduce their speed, proceed with caution, etc. The other most common answer was that the driver would look around; be more perceptive; try to figure out what is happening ahead.

Table 5.1: Summary of Answers to "What Would Motorist Do When They See the Arrow Panel Display?"

Category of Answer	Flashing Line n = 92	Flashing Four-Corner n=89	Sequentially Flashing Diamond n=93
Slow down; be cautious	68 (74%)	62 (70%)	68 (73%)
Change lanes	1 (1%)	2 (2%)	2 (2%)
Don't know	4 (4%)	2 (2%)	3 (3%)
Look around to try to figure out what is going on	10 (11%)	5 (6%)	8 (9%)
Other	9 (10%)	18 (20%)	12 (13%)

The verbatim responses recorded for the "Other" category were varied. For example, one respondent, viewing the four-corner display, answered "I would be totally confused by that sign. It looks like it's malfunctioning, but I guess I would slow down." Another who looked at the four-corner display said "Slow down – because it's yellow. I don't know what the four dots mean." A person looking at the diamond display answered: "I would wonder what it means at first. Then I would yield." A person given the line display to look at responded: "That's *[the line display*] kind of a neutral one; probably do nothing."

5.2.2 Question 2 – Effectiveness of the Displays

The second question asked drivers to look at all three displays. The interviewer explained that the three flashing signs [*arrow panel displays*] were intended to alert drivers when they are approaching a temporary work zone. The interviewer then asked "Which one of the three flashing signs is most effective in getting your attention?" Figure 5.1 provides the distribution of responses.

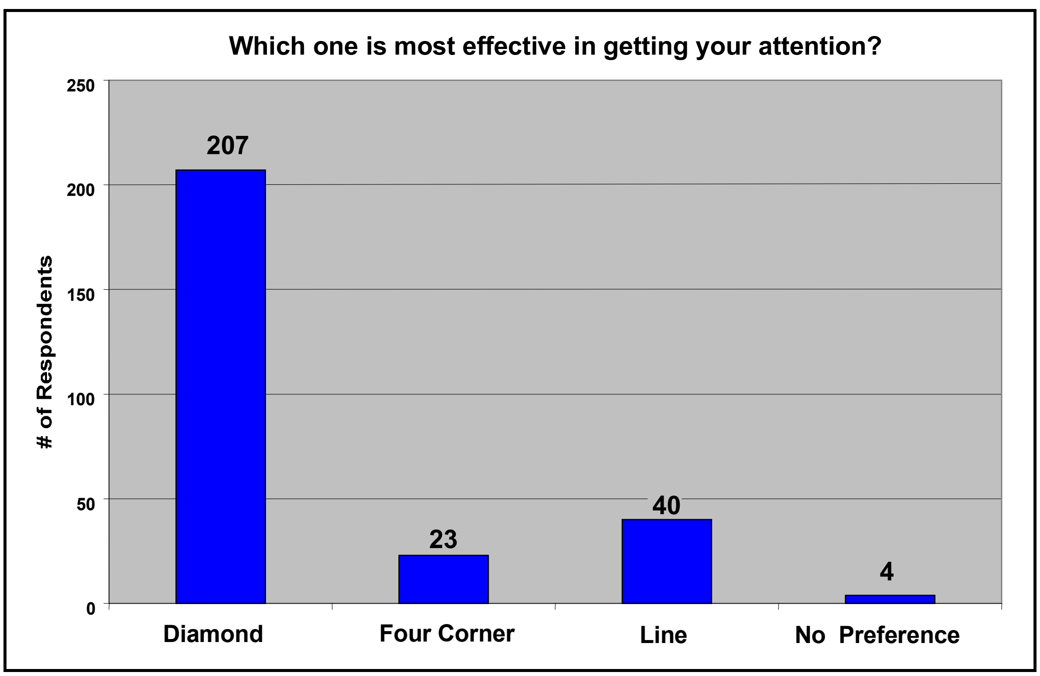


Figure 5.1: Distribution of Responses about Most Effective Display

More than 75% selected the diamond as most effective, followed by the line display (15%) then the four-corner (8%). Only 4 respondents felt there was no single display that was most effective. The respondents were then asked why the display they chose was most effective. The following is a synopsis of the responses.

Diamond

Thirty-four said the diamond was effective because of the alternate flashing pattern. Twenty-nine said there were more lights flashing on the diamond pattern, or it looked bigger. Twenty-two indicated it looked brighter or had motion. Eighteen said the diamond pattern indicated caution. Eight mentioned it has more impact and it's moving. Many of the other responses were similar but varied slightly.

Line

Eleven said that the line pattern was brighter or stood out more. Ten said the flashing line had more lights on. Three said that it had the greatest contrast. The other responses varied.

Four-corner

Eight said the four-corner looked brighter. Three commented about the display having four separate lights to look at. Two said the lights were all flashing; they [*lights*] cover a bigger area. The other comments varied.

5.2.3 Question 3 – Ease in Seeing the Displays

Motorists were asked: "Which one flashing sign is easiest for you to see?" Figure 5.2 shows a summary of the responses.

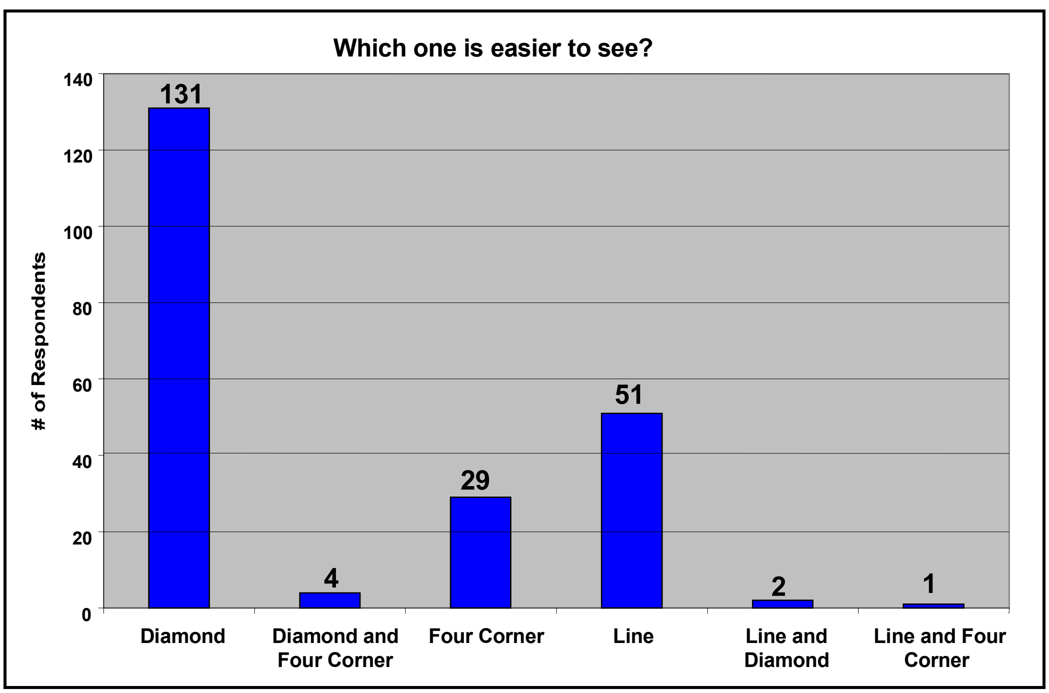


Figure 5.2: Distribution of Responses about which Display was Easiest to See

Clearly, most (63%) felt that the diamond display was easiest to see, with 25% choosing the line display and 16% the four-corner mode. Seven respondents felt that two displays were equally easy to see. Drivers were asked why it was easier to see the display they chose. The following is a synopsis of the responses.

Diamond
Fifty drivers said the diamond display was easier to see because it alternates back and forth. Twenty-three said the diamond had more lights. Ten said it was easier to see because of a bigger display. Four said it was brighter. Nine said the display was moving. The other responses related somewhat to, either movement, lighting configuration, or the alternating pattern.

Line
Fifteen said that the line display was brighter. Nine said that it was easier to see because of the straight line pattern. Five said that the flashing line had more lights on. Three said that it had the greatest contrast. The other responses varied slightly but were related to the other comments about the line display.

Four-corner
Thirteen said the four-corner display looked brighter. Three commented about the display having four separate lights to look at. Two said it was easier to see because the lights flashed all at one time and covered a bigger area. The other comments varied.

5.2.4 Question 4 – Confusion About What Action to Take

The next question asked drivers: "Do any of these flashing signs confuse you about what action you should take?" Figure 5.3 provides a summary of the responses.

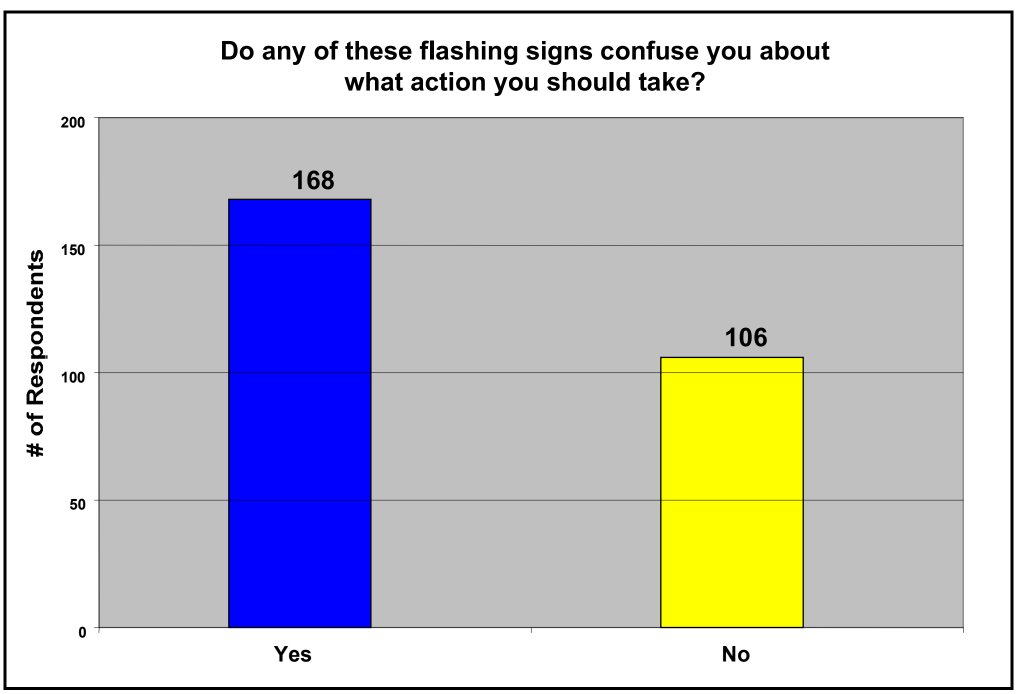


Figure 5.3: Distribution of Responses about Displays Confusing Motorists

The 168 people who found one or more of the of the displays confusing were then asked: "Is one of the three flashing signs more confusing to you than the others?" All of the signs were confusing to 40 respondents. The remaining 128 were able to identify one or more displays that were most confusing. The distribution of responses is shown in Figure 5.4.

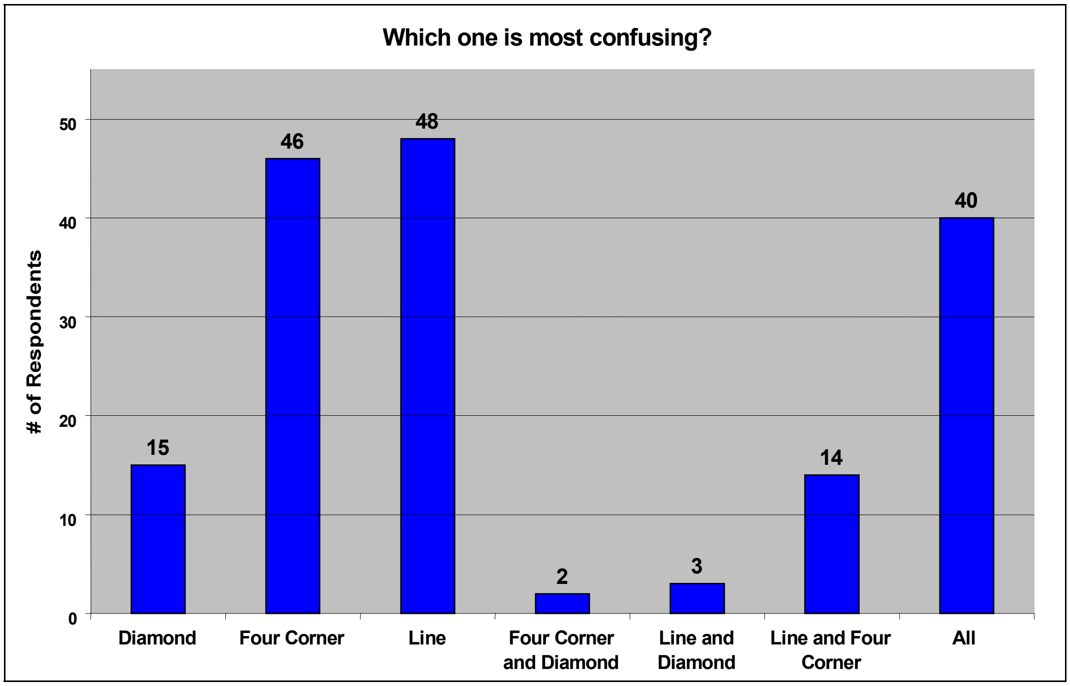


Figure 5.4: Distribution of Responses Showing which Display Confused Drivers

Although drivers where asked to identify one display as most confusing, some (35%) listed more than one, as can be seen in the distribution. Almost 63% of the respondents felt the line display was the most confusing. Nearly as many (61%) found the four-corner display confusing, while 36% were confused by the diamond mode. When the respondents were asked why they were confused, they gave the following responses.

<u>Diamond</u>

Many of the 15 drivers that found the diamond display confusing said they were not sure if it meant to change lanes. Others said the display did not tell them to do anything, or said they didn't know what the display meant.

<u>Line</u>

Thirty-two said the line display did not mean anything. Fifteen people mentioned that the flashing line looked like an arrow that was missing the head. Eleven were confused because this display did not resemble any other sign.

<u>Four-corner</u>

The majority of respondents who found the four-corner display confusing said it was because they had not seen it before and/or did not know the meaning of the display. Other drivers were confused because they felt the display did not tell them what to do.

5.2.5 Question 5 – Displays Suggest a Lane Change

Motorists were asked: "Do any of these flashing signs suggest that you change lanes?" Figure 5.5 shows a summary of the responses. The 78 (28%) who answered yes were asked: "Which display suggests that you change lanes?" Figure 5.6 provides the distribution of responses.

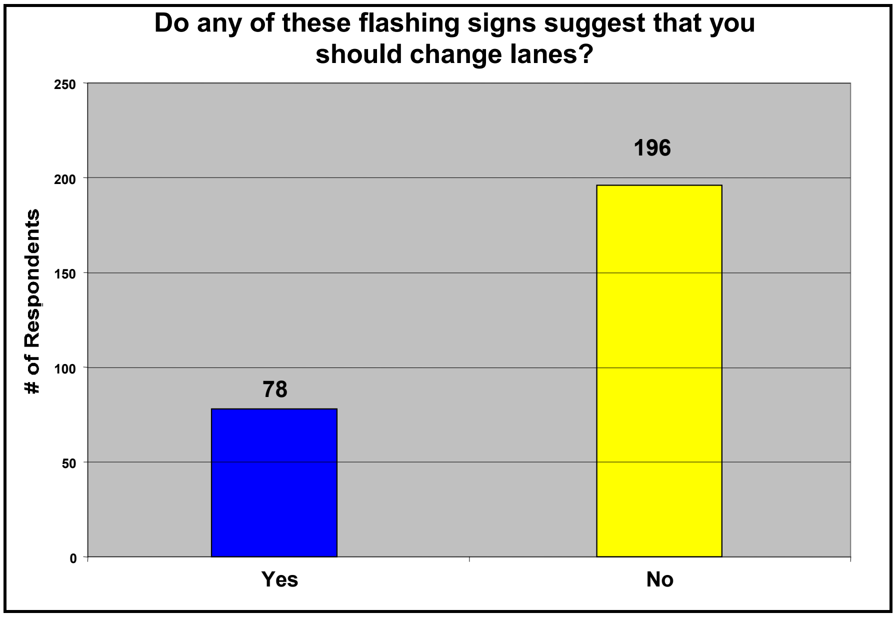


Figure 5.5: Distribution of Responses if Display Suggested Lane Changes

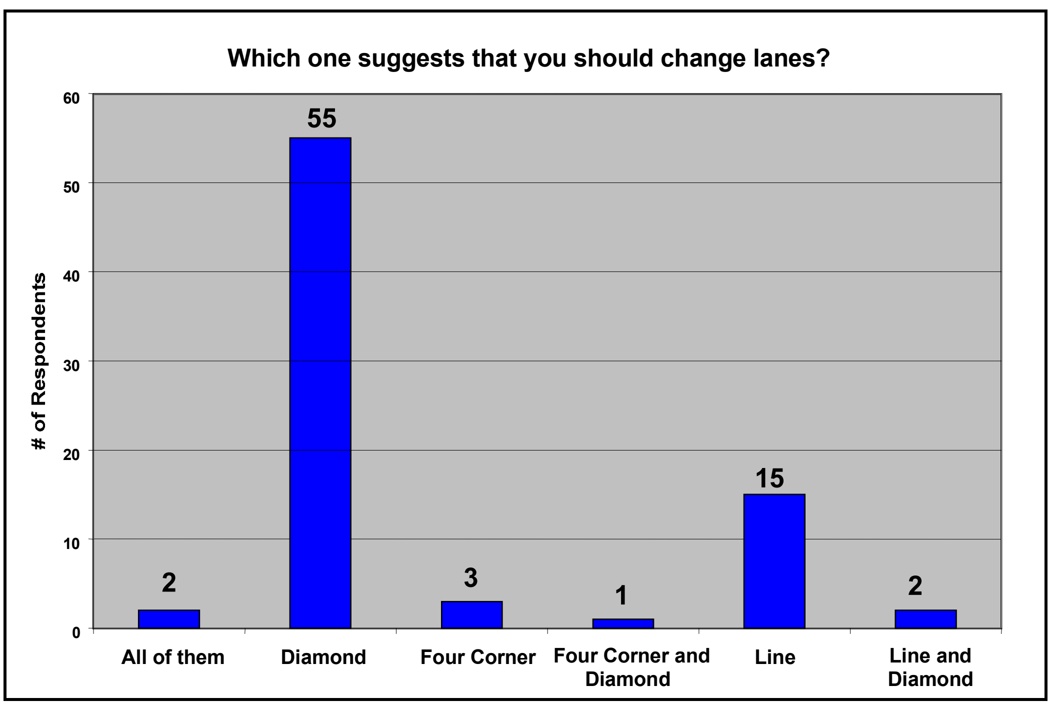


Figure 5.6: Distribution of Responses Showing which Displays Suggested Lane Changes

It is interesting to note that, while 78 respondents said that the signs suggested a lane change, only 5 had mentioned, in response to Question 1, that they would change lanes after they viewed the initial display.

5.2.6 Question 6 – Driver Preference About Displays

Figure 5.7 shows the distribution of responses when participants were asked “As a driver, which one flashing sign would you like to see used when work is taking place on Oregon highways?”

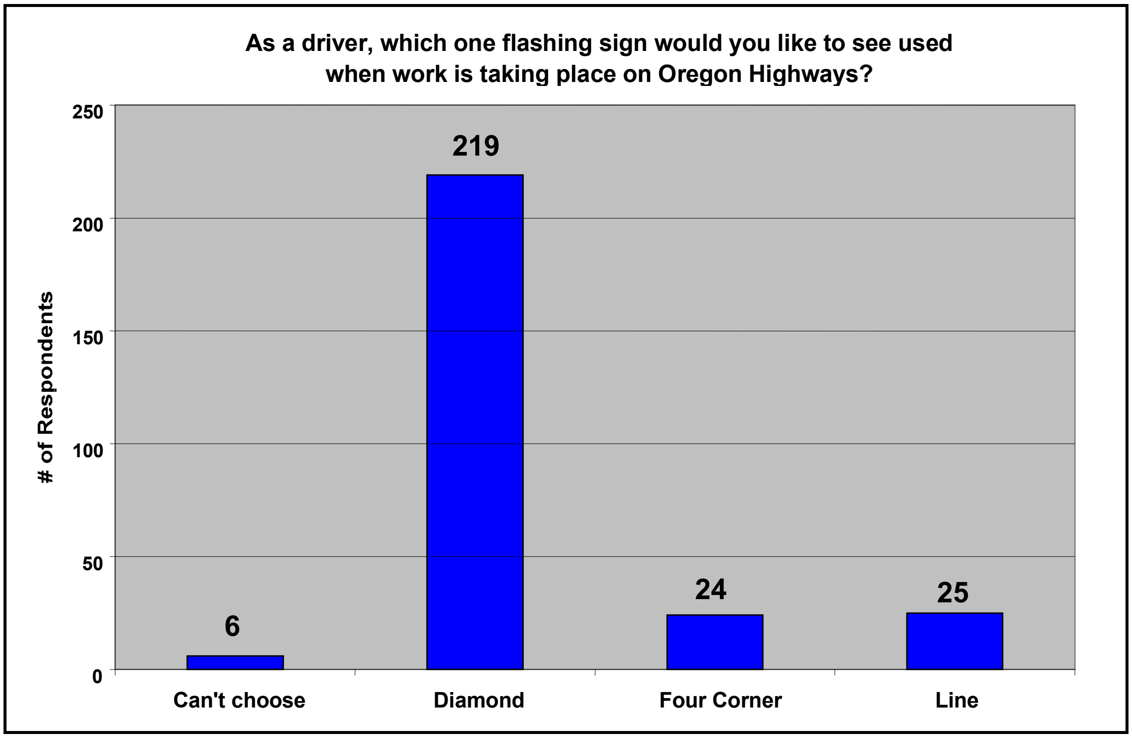


Figure 5.7: Distribution of Responses about Drivers’ Preferences

Overwhelmingly, respondents selected the diamond display, with about 80% preferring it, while about 9% selected either the four-corner or line modes. Motorists were then asked to make a second choice about their preferences for which display they would like to see used. Their responses are show in Figure 5.8.

As their preferred second choice, an additional 10% selected the diamond mode to warn drivers approaching work zones. Again, the four-corner and line displays received a similar number of votes, with about 25% of respondents selecting each as their second choice.

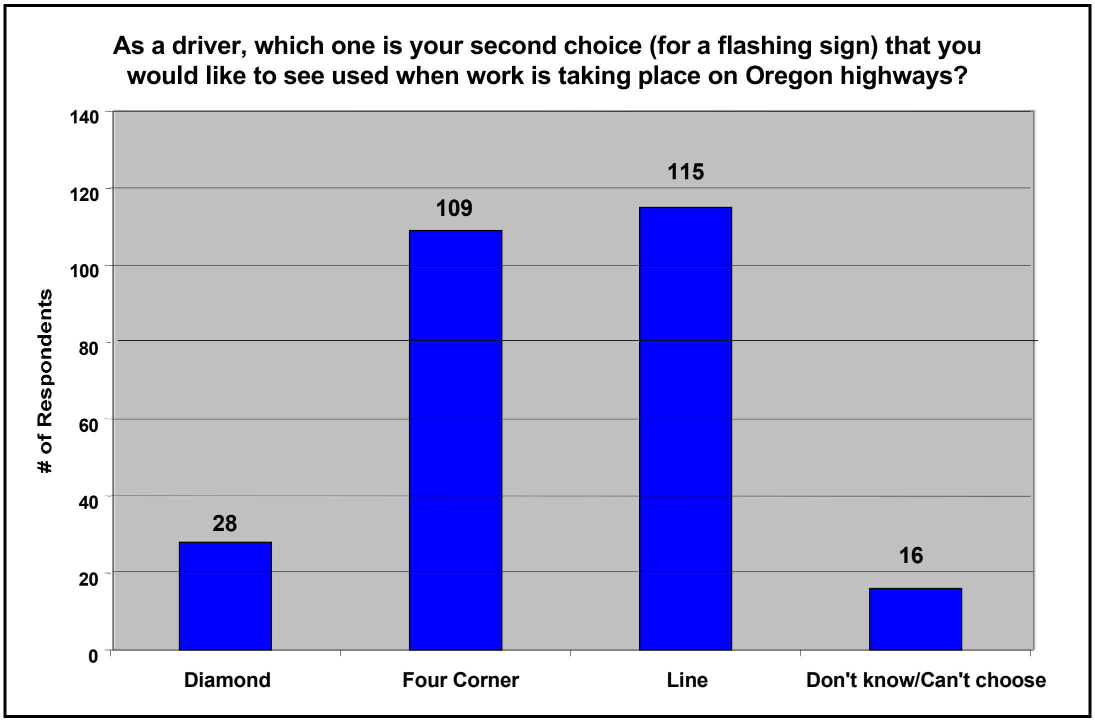


Figure 5.8: Distribution of Responses about Drivers' Second Choice

5.2.7 Question 7 – Preferences about the Displays from the a Highway Worker's Perspective

Drivers were asked: If you were a state highway worker, which flashing sign would you like used when working on Oregon highways?" The responses were similar to the pattern of answers in Question 6. There were 202 people who chose the diamond display. Twenty-six picked the four-corner and 30 chose the line display. Sixteen couldn't make a clear distinction or didn't know which one to choose.

5.2.8 Questions 8-11 – Driver Experience

Motorists were also asked about their own driving experience. Figure 5.9 provides a summary showing the years of driving experience reported by respondents.

The modal class (highest occurring frequency) is 25-30 years. The actual average years of driving experience for the 274 respondents is 27.7 years. However, the distribution is very dispersed, and at least 5% of the drivers comprised each category.

A cross-tabulation table was created to analyze the years driving experience and the distribution of responses to the question, "Which display is the most effective at getting your attention?" The results (Figure 5.10) show that for every 5-year experience category (except 46-50 years), 70% or more respondents chose the diamond display. Within the 46-50 year experience category, 8 of 15 (54%) respondents chose the diamond display as the most effective.

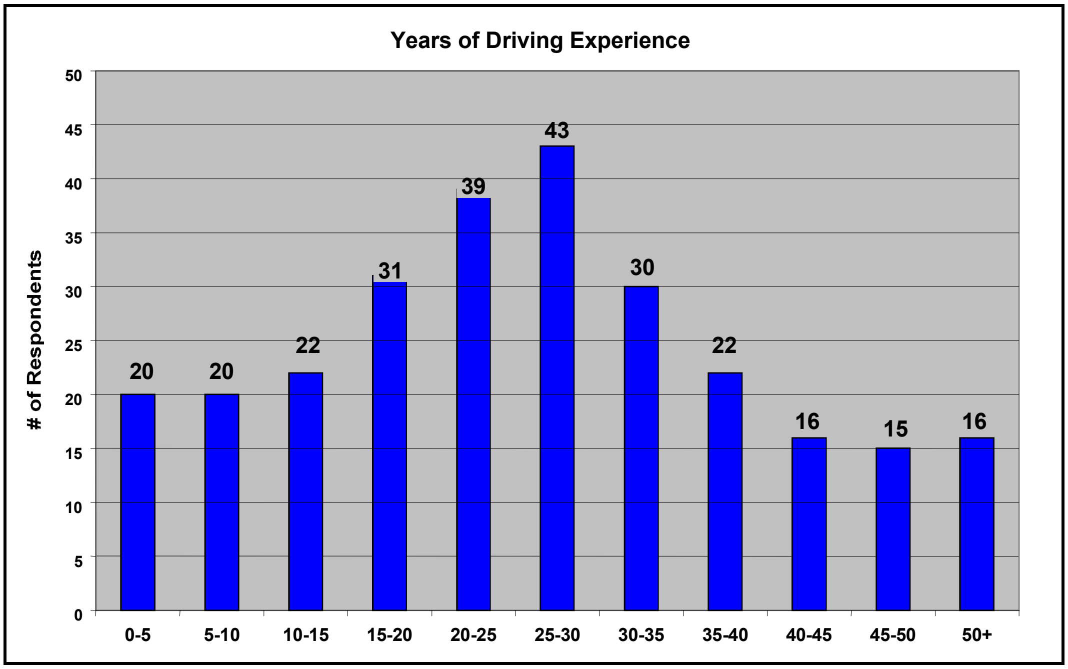


Figure 5.9: Distribution of Years of Driving Experience

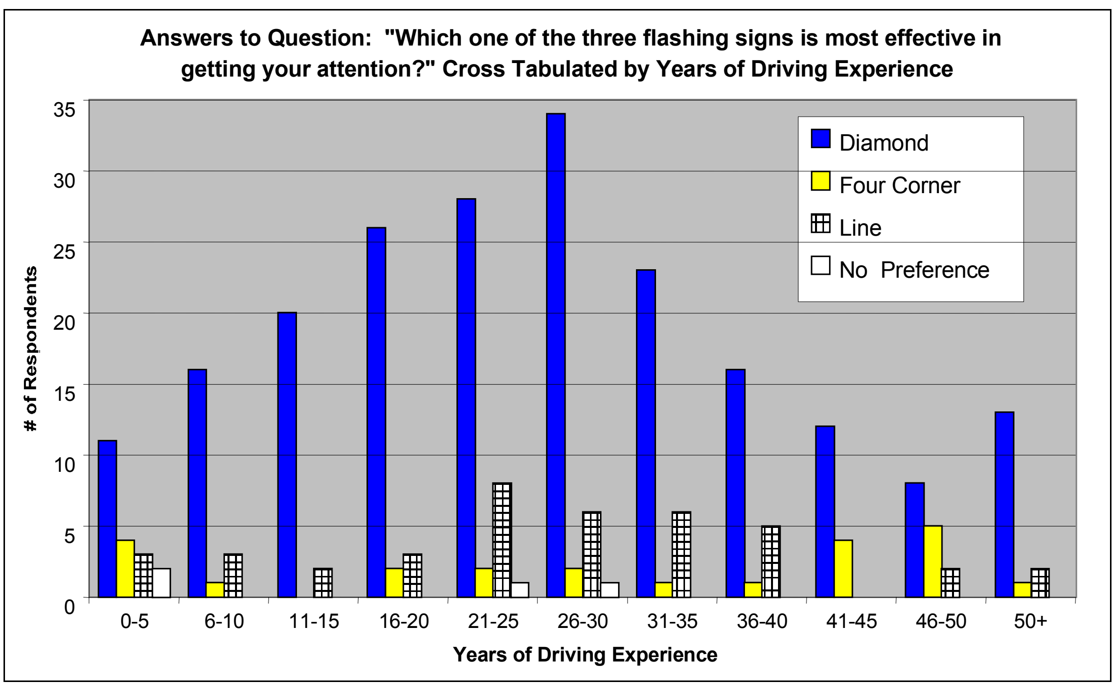


Figure 5.10: Cross Tabulation Results Showing the Most Effective Display by Years of Driving Experience

5.2.9 Question 9 – Respondents Who Drive as Part of their Job

The survey also asked people: "Do you drive as part of your job?" and, "If yes, are you a truck driver?" There were 68 people (25%) that drive as part of their job and another 28 (10%) were truck drivers. A cross tabulation was done to see if there were differences in opinions about the effectiveness of the displays, comparing responses of people who drive as part of their occupation to responses of truck drivers. The results of the cross tabulation are shown in Figure 15.11.

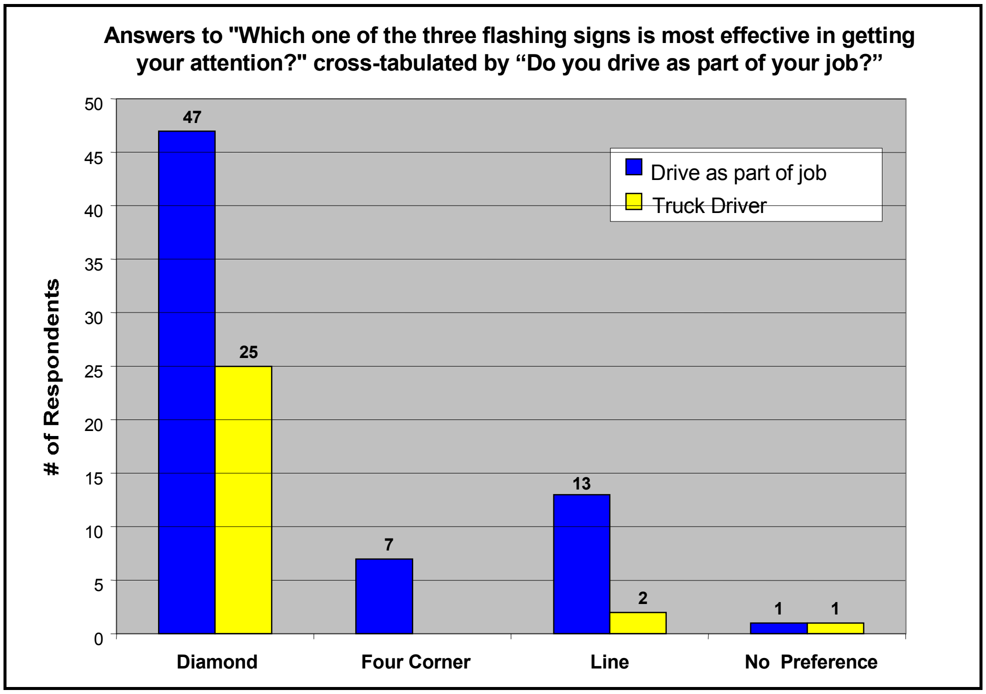


Figure 5.11: Cross Tabulation Results Showing the Most Effective Display by Type of Driver

Almost 90% (25 of 28) of the truck drivers chose the diamond display. Of those grouped in the "other" driver category (sales representatives, bus drivers, etc.), 69% (47 of 68) also chose the diamond display as the most effective. When considered together, 75% (72 of 96) of the "professional drivers" selected the diamond display, which is about the same proportion as the entire survey population (76%) that is represented in Figure 5.1.

5.2.10 Question 10 and 11 – Vision Difficulties

People were also asked if they were color-blind. The overwhelming majority of respondents said they were not. Only 14 reported that they were color-blind. Because of the low number of responses, no statistically valid analysis of the effects of color-blindness could be done.

Another vision question asked: "Do you wear corrective lenses (such as contact lenses or prescription eyeglasses) or have any other difficulty seeing?" Most of those surveyed (60% or 165) answered yes. To see if there were any differences in how people who have vision problems answered the question about which display was most effective, the answers to the two questions were cross tabulated. The results are shown below in Table 5.2.

Table 5.2: Cross Tabulation Results Showing the Most Effective Display by Vision Difficulty

	Which one of the three flashing signs is most effective in getting your attention?				
Do you wear corrective lenses or have other difficulties seeing?	**Diamond**	**Four Corner**	**Line**	**No Preference**	Grand Total
Yes	122 (73%)	19 (11%)	23 (14%)	2 (1%)	166
No	83 (77%)	4 (4%)	17 (16%)	4 (4%)	108
Grand Total	207	23	40	4	274

Proportionately, the percentages of people choosing the diamond as the "most effective" display was about the same for those who wore corrective lenses (or had vision difficulty) as those who did not. About 73% (122 of 166) of people who wore corrective lenses (or had difficulty seeing) chose the diamond display, compared to almost 77% (83 of 108) of people who did not have vision problems. The four-corner display was chosen as the most effective by 11% (19 of 166) of the people who wore corrective lenses, compared to less than 4% (4 of 108) of those who did not wear corrective lenses. The percentages of those choosing the line display were about the same for both vision categories.

5.3 DISCUSSION OF SURVEY RESULTS

The survey results make a strong case for the use of the diamond display in temporary work zones. Of the 274 respondents, 207 (76%) chose the diamond display as the most effective of the three in getting their attention. According to 60% (131 of 218), the diamond was easier to see, and 80% (219 of 274) preferred the use of the diamond display when work is taking place along Oregon highways.

Driver confusion with the arrow panel displays is high, with 61% (168 of 274) finding the displays confusing. Of these 168 respondents, the fewest (9%) found the diamond display most confusing, while 27% were confused by the four-corner and 29% by the line display. Still, many found more than one display confusing, with 23% confused by all displays, and 8% by the line and four-corner displays. Only 2% found both the line and diamond confusing, and 1% were confused by both the diamond and four-corner displays.

The cross tabulations showed that across all driving experience levels, the diamond display was chosen as the most effective. In addition, almost all of the truck drivers who were surveyed picked the diamond display as being the most effective.

About 29% (78 of 274) of those surveyed thought that one or more of the displays suggested a lane change. Further, 77% of the 78 chose the diamond display as the one that suggested a lane change. However, of the 55 who chose the diamond display as the one suggesting a lane change, 37 also chose this display as their preference when work is taking place along Oregon highways. Alternatively, of the 219 respondents who preferred the diamond display to be used in work zones, 179 (82%) did not think the diamond display meant to change lanes. Figure 5.12 illustrates this finding. The pie chart shows the distribution of responses to the drivers' preferences about display type. The bar graph further details opinions of the 219 drivers who chose the diamond display, by showing how many of these drivers believed an arrow panel display designated a lane change. One-hundred-seventy-nine did not choose the diamond display when asked “Which one suggests that you should change lanes?” Most (164) said none of the displays suggested a lane change. Twelve chose the four-corner and three people chose the line display.

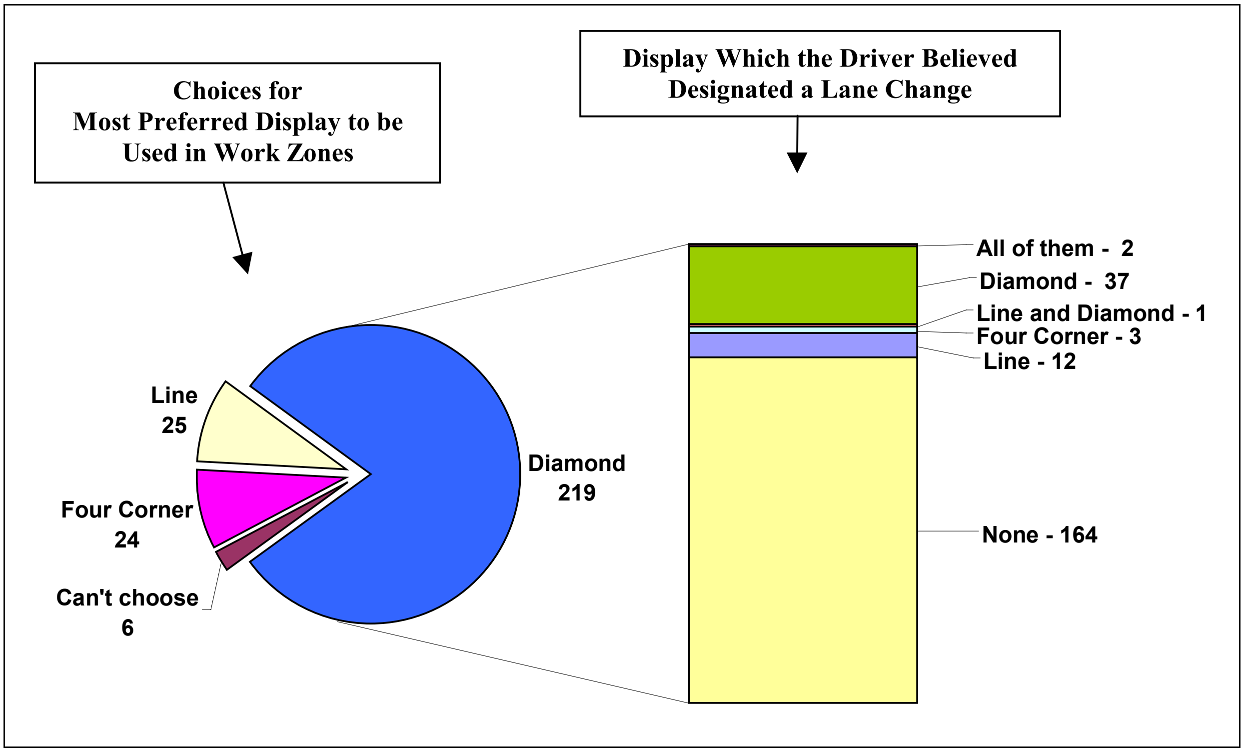


Figure 5.12: Distribution of Responses Comparing Diamond Display Preferences and Which Display Directed a Lane Change

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The results of the state DOT survey showed that most states are using the line and four-corner arrow panel displays as an advance warning device in temporary work zones. There was some reported use of the diamond display by five states. In rating the displays, it is apparent from the survey data that there was no one clear preferred display over another.

The arrow panel display field trials on OR Route 22 and OR Route 99W provided noteworthy results. Hourly average and 85^{th} percentile speeds decreased from the 30-day baseline speeds for each display mode. Chi-square testing for independence showed that there was no statistical relationship between the display type and lane and speed distribution except for one 3-hour period. In this afternoon period at the OR Route 22 site, a statistical relationship was established between the arrow panel display mode and the speed distribution.

In comparing the test day data to the baseline, the greatest reductions in average and 85^{th} percentile speeds for most three-hour periods, occurred when the diamond display was operating. Further, the lane distribution shifts at the OR Route 22 site were greatest during the hours the diamond display was in use. The field trials demonstrated that the diamond display performed as well, if not better than, the line or four-corner displays.

The motorist surveys demonstrated the usefulness of the diamond display mode as an advance warning device for temporary work zones. Over 75% of those surveyed chose the diamond display as the most effective at getting their attention. However, the majority (61%) of those who were surveyed found the three displays confusing, particularly the line and the four-corner. In addition, about 29% of the 274 surveyed (78 respondents) indicated the displays suggested a lane change, including 55 who thought the diamond display meant to change lanes. This large number of respondents who are confused or misled indicates a lack of understanding about the meaning of these “caution” displays. Although there was evidence of motorist confusion, 80% of the respondents said they would like to see the diamond display used when work is taking place on Oregon highways.

The results of the field trials and motorist survey show considerable potential for using the diamond display as an advance warning device in temporary work zones.

6.2 RECOMMENDATIONS

1. Greater emphasis should be given to educate the traveling public about the use of caution modes on arrow panel displays.

2. The results of this research should be used to complement the similar study being conducted by the Utah DOT.

3. The diamond display should be considered for use as an alternative to the line and four-corner displays for advance caution warning when working on the shoulder or alongside the roadway.

7.0 REFERENCES

Bryden, J.E. *Effectiveness of Flashing Arrow Boards During Moving Maintenance Operations.* State of New York Department of Transportation Research Report 73, Albany, New York, 1979, pp. 1-19.

Fortey, N. Federal Highway Administration, Oregon Division. Letter to the author, June 8, 2001.

Knapp, B.G. and R.F. Pain. Human Factors Considerations in Arrow-Board Design and Operation. In *Transportation Research Record 703*, TRB, National Research Council, Washington, D.C., 1979, pp.1-36.

Mace, D., M. Finkle and S. Pennak. Photometric Requirements for Arrow Panel Visibility. In *Transportation Research Record 1553*, TRB, National Research Council, Washington, D.C., 1996, pp. 66-72.

Utah Department of Transportation (UDOT), Division of Research. *Scope of Work: Evaluating the Effectiveness of "Dancing Diamond" Caution Mode as an Early Work Zone Warning Device*. October 18, 2000.

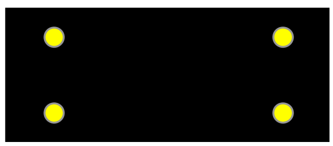
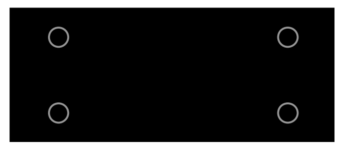
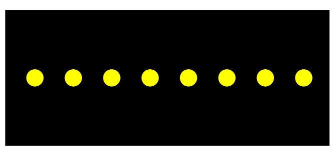
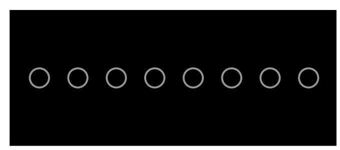
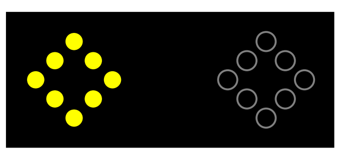
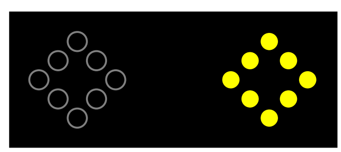
Appendix A

DOT Survey Questionnaire

ARROW PANEL DISPLAYS FOR INDICATING “CAUTION”

When work is taking place on the shoulder, or alongside the shoulder off the roadway, the Oregon Department of Transportation uses arrow panel displays as an advance warning device. In the past, prior to the development of the 2000 MUTCD, the Department has used three possible display modes during mobile operations like striping and sweeping as well as static operations on the shoulder or alongside the roadway. The intent of this survey is to learn about arrow panel display modes used in other state DOTs across the nation. This survey will contain a series of questions about three arrow board display modes shown below. We wish to know about your agency’s experience with each of the three displays. Therefore, we would like the appropriate person within your agency to assist us by completing this short survey.

Thank you very much for your help and participation.

Display Type	First Sequence	Second Sequence
Option A: ***Flashing Four-Corner***		
Option B: ***Flashing Bar***		
Option C: ***Flashing Diamond***		

Note: the displays shown above flash from sequence one to sequence two, then back to sequence one.

1. Does your agency use any of the three advance warning arrow displays (Options A, B, and C) for slow moving operations like striping or sweeping as well as static operations on the shoulder work or alongside the roadway?
   Yes No

2. If Yes, Which display /displays has your agency used (you may select more than one)?
   A B C

3. For the arrow display devices your agency has used, on what types of work has your agency used them (e.g. striping, sweeping, ditch cleaning, mowing, guardrail replacement, etc.)?

Option A

Option B

Option C

4. Based on your experience, please rate on a scale from 0 to 5, the effectiveness of each display mode option shown above as an advance caution warning to drivers.

   5 - Highly Effective;
   4 – Reasonably Effective;
   3 - Effective;
   2 – Marginally Effective;
   1 – Not effective;
   0 – No basis for opinion because we don't use this display.

Option A:	0	1	2	3	4	5
Option B:	0	1	2	3	4	5
Option C:	0	1	2	3	4	5

5. Do you have any other comments you wish to add?

Thank you again for your help and participation. Additionally, in case we wish to contact you at a later date, can you please provide the following information:

Agency:

Address:

Questionnaire completed by:

Title: Fax:

Telephone: E-mail:

Appendix B

Motorist Survey Questionnaire

ODOT "ARROW" SURVEY

Interviewer Number _______________

TIME ____________________________

LOCATION: *1* ❑ SOUTH *2* ❑ NORTH

OREGON SURVEY RESEARCH LABORATORY
5245 UNIVERSITY OF OREGON
EUGENE, OR 97403-5245
TELEPHONE: 541-346-0824
FACSIMILE: 541-346-0388
EMAIL: OSRL@OREGON.UOREGON.EDU
WWW: DARKWING.UOREGON.EDU/~OSRL

INTERVIEWER: Q1 REFERS TO THE FLASHING SIGN THAT LOOKS LIKE THIS: 

**Q1. Please look at the flashing sign labeled <u>number two</u> on the back of the truck.
Imagine that you are driving down the highway, and you see this flashing sign.
<u>What would you do</u> (if you saw this flashing sign)?**
PROBE: What does this flashing sign tell you to do?
PROBE: What do you think this flashing sign means?

**Q2. Now please look at <u>all</u> <u>three</u> flashing signs on the trucks.
The signs' purpose is to tell drivers that a temporary highway work zone is ahead on the road.
Which <u>one</u> (of the three flashing signs) is <u>most</u> <u>effective</u> in getting your attention?**
PROBE: If you had to choose, which one (flashing sign) is <u>most</u> <u>effective</u> in getting your attention?
IF "CAN'T CHOOSE," "ANY IS FINE," OR "DON'T KNOW," CHECK HERE ❑ *(9)*, THEN → SKIPTO Q3.

1 ❑ **Straight Line**	*2* ❑ **Four Corner**	*3* ❑ **Diamond**
Q2a. Why (is it most effective)?	**Q2a. Why (is it most effective)?**	**Q2a. Why (is it most effective)?**

Q3. Is one of the three flashing signs easier for you to see?

PROBE: If you had to choose, could you say that one (flashing sign) is somewhat easier for you to see than the others?

1 ❑ YES ↓ *2* ❑ NO → SKIPTO Q4

Q3a. Which one (is easier) (for you to see)?

(CHECK ALL THAT R MENTIONS.)

(RECORD ANY COMMENTS R MAKES ON SIGNS IN PROPER COLUMN.)

1 ❑ **Straight Line**	*2* ❑ **Four Corner**	*3* ❑ **Diamond**
Q3b. Why (is it easier for you to see)?	**Q3c. Why (is it easier for you to see)?**	**Q3d. Why (is it easier for you to see)?**

Q4. Do any of these flashing signs confuse you about what action you should take?

1 ❑ YES ↓ *2* ❑ NO → SKIPTO Q5

Q4a. Is one (of the three flashing signs) more confusing to you than the others (about what action you should take)?

1 ❑ YES ↓ *2* ❑ NO, ALL ARE CONFUSING → CHECK ALL, ASK Q4c,d,e

Q4b. Which one is most confusing (to you) (about what action you should take)?

(CHECK ALL THAT R MENTIONS.)

(RECORD ANY COMMENTS R MAKES ON SIGNS IN PROPER COLUMN.)

1 ❑ **Straight Line**	*2* ❑ **Four Corner**	*3* ❑ **Diamond**
Q4c. Why (is it confusing)?	**Q4d. Why (is it confusing)?**	**Q4e. Why (is it confusing)?**

Q5. Do any of these flashing signs suggest that you should change lanes?

1 ❑ YES ↓ *2* ❑ NO → SKIPTO Q6

Q5a. Which one(s) (suggest(s) that you should change lanes)?
(CHECK ALL THAT R MENTIONS.)
(RECORD ANY COMMENTS R MAKES ON SIGNS IN PROPER COLUMN.)

1 ❑ **Straight Line**	*2* ❑ **Four Corner**	*3* ❑ **Diamond**
Q5b. How? (does it suggest that you should change lanes)?	**Q5c. How? (does it suggest that you should change lanes)?**	**Q5d. How? (does it suggest that you should change lanes)?**

Q6. As a driver, which <u>one</u> flashing sign would <u>you like to see used</u> when work is taking place on Oregon highways?

PROBE: If you had to choose, which one (flashing sign) would you prefer to see (when work is taking place on Oregon highways)?

IF "CAN'T CHOOSE," "ANY IS FINE," OR "DON'T KNOW," CHECK HERE ❑ *(9)*, THEN → SKIPTO Q7.

1 ❑ **Straight Line**	*2* ❑ **Four Corner**	**3** ❑ **Diamond**
Q6a. Why? (would you like to see that one used)? (when work is taking place on Oregon highways)?	**Q6b. Why? (would you like to see that one used)? (when work is taking place on Oregon highways)?**	**Q6c. Why? (would you like to see that one used)? (when work is taking place on Oregon highways)?**

Q6d. As a driver, which one is your second choice (for a flashing sign) (that you would like to see used when work is taking place on Oregon highways)?

1 ❑ STRAIGHT LINE *2* ❑ FOUR CORNER *3* ❑ DIAMOND

Q7. If you were a <u>state highway worker</u>, which flashing sign would you like used when working on Oregon highways?	*1* ❑ STRAIGHT LINE *2* ❑ FOUR CORNER *3* ❑ DIAMOND *4* ❑ ANY OF THE ABOVE *8* ❑ DON'T KNOW / CAN'T CHOOSE *9* ❑ OTHER (SPECIFY)___________________

Q8. For how many years have you been driving?	NUMBER OF YEARS___________________ *0* ❑ <1 YEAR *99* ❑ NO DRIVERS LICENSE NOW
Q9. Do you drive as a regular part of your job? IF YES: Are you a professional truck driver?	*1* ❑ NO *2* ❑ YES, PROFESSIONAL TRUCK DRIVER *3* ❑ YES, OTHER DRIVER *4* ❑ OTHER (SPECIFY)___________________
Q10. Are you color blind?	*1* ❑ YES *2* ❑ NO *3* ❑ OTHER (SPECIFY)___________________
Q11. Do you wear corrective lenses (such as contact lenses or prescription eyeglasses) or have any other difficulties seeing	*1* ❑ YES *2* ❑ NO

Q12. If there is one thing ODOT could change or improve to make you feel safer in highway work zones, what would if be?

PROBE: Please think about <u>safety</u> in highway work zones.

INTERVIEWER OBSERVATION:

Q13. R'S APPROXIMATE AGE GROUP:

1 ❑ < 25 YEARS OLD
2 ❑ 25 - 39 YEARS OLD
3 ❑ 40 - 59 YEARS OLD
4 ❑ 60+ YEARS OLD

Q14. R'S SEX:

1 ❑ MALE
2 ❑ FEMALE