Arrow Panel Display Evaluation in Temporary Work Zones

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Abstract

The Oregon Department of Transportation evaluated the effectiveness of a "sequentially flashing diamond" arrow panel display as an advance caution warning in temporary work zones. This display was evaluated by comparing it to flashing line and flashing four-corner modes. When surveyed, 33 state transportation agencies rated each display about the same in terms of effectiveness. Daytime and nighttime field trials using the three modes were conducted in two work zones set up on highway shoulders. Nine hours of evaluation time at each site was divided into three, three-hour test periods, with each display operating for one hour. 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 occurred when the diamond display was operating.

Additionally, motorists at a highway rest area were surveyed about the three 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, and80% said they would like to see the diamond used when work is taking place on Oregon highways. However, 61% found the three displays confusing, particularly the line and the four-corner. The results of the field trials and motorist survey show potential for the diamond display's use as an advance warning device in temporary work zones.

BACKGROUND

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

The 2000 edition of the Manual for Uniform Traffic Control Devices (MUTCD 2000) describes four types of arrow panels (A, B, C, and D). Each has different minimum size requirements, legibility distance standards, and number of elements. ODOT uses Type B and C arrow panel displays as an advance warning device for maintenance operations.

The Type B and C panels can display a variety of "caution" modes to provide advance warning to drivers. The caution displays 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. The MUTCD 2000 prescribes either the flashing four-corner or the flashing line for use as caution mode displays. The arrow panels can also display a third caution mode, the sequentially flashing diamond. These three displays are shown in Figure 1.

Since the sequentially flashing diamond mode is not prescribed in the MUTCD 2000, ODOT crews are not using this display. However, maintenance crews working in Oregon's most populated area, the Willamette Valley, expressed a strong desire to use the sequentially flashing diamond as a caution mode display. Consequently, ODOT decided to evaluate all three modes to determine the effectiveness of each display. FHWA granted permission to test and evaluate non-MUTCD compliant caution modes in temporary work zones set up to research the effects of the displays on traffic (*1*).

RESEARCH OBJECTIVES AND METHODOLOGY

The objective of the research was to evaluate the effectiveness of the sequentially flashing diamond as an advance warning device by comparing it to the two other flashing modes (line and four-corner). The research would help determine which flashing mode should be used when work is taking place on or near the roadway in stationary or slow moving work zones.

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

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) on their usage of arrow panel displays, and what mode(s) they are using for static and slow moving operations on the shoulder or off the roadway.
3. Field tests in which the three flashing modes were used in temporary work zones. The effectiveness of each mode was assessed at two locations; one being a two-lane highway, and the other a multi-lane highway.
4. A survey of motorists to obtain their perceptions about each display mode.

For brevity, for the rest of the paper, the use of “flashing” and “sequentially flashing” will be omitted when discussing the three display modes. The display modes will be referred to, as simply, “line”, “four-corner” and “diamond.”

LITERATURE REVIEW

Research on arrow panel displays is limited. Knapp and Pain (*2*) investigated driver responses to different arrow panel displays. They tested various flashing and sequentially flashing displays including the arrow, double arrow, chevron, and two caution modes, the four-corner and line. (Their line display used only five lights illuminated along the horizontal axis in the center of the panel.) The researchers conducted a survey using a series of nine film clips showing arrows, chevrons, and the two caution displays from the perspective of a driver seeing them as he or she approached the arrow panel. After each film clip, which depicted a different display mode in the travel lane or on the shoulder, the 20 viewers were asked to select one of four responses about what action a driver should take when seeing the display. The researchers noted the caution modes (four-corner and partial line) caused confusion, with more than half of the respondents misinterpreting their meaning. They 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” (*2*).

Bryden (*3*) 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*], as well as a smaller-size board with a sequential chevron display. Both modes were used 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.

The Utah Department of Transportation (UDOT) is currently conducting research to compare the effectiveness of the flashing diamond with the MUTCD recommended modes. 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 the diamond and other caution warning signs will be videotaped. Participants will be tested for their understanding and identification of the warning signs as they watch the videotaped work zones. In the field study, work zones will be randomly selected and data on performance measures to be used for the hypothesis testing will be collected. UDOT’s study is in progress, with results expected by January 2002 (4).

SURVEY OF OTHER STATE DOTS

Other State DOTs were surveyed using an internet-based survey questionnaire to obtain information about their use of arrow panel displays. The DOTs were contacted through the American Association of Highway and Transportation Officials (AASHTO) Research Advisory Committee, who forwarded a hyperlinked electronic questionnaire to the most appropriate person in their agency. Of 33 states that responded, 27 indicated that their states use arrow panel displays for static work zones and slow moving operations. States were asked to identify which displays they have used. Twenty have used the four-corner display; 15 said the line display and 6 have used the diamond display. The four states bordering Oregon reported the following use:

- Four-corner – Idaho, California, Nevada, Washington
- Line – Idaho, Nevada
- Diamond: - Idaho, California

States were also asked to rate the effectiveness of each of the display modes they have used on a scale of 1-5, with “1” representing “not effective” and “5” as “highly effective.” Most agencies only rated the display modes they were using. Those not familiar with a particular display mode typically checked “no opinion.” Figure 2 shows the distribution of the responses. The mean score for the four-corner display was 3.19 (s=0.93); the line’s mean score was 3.38 (s=1.15). The diamond display had the highest mean score, at 3.5 (s=1.05), receiving “effective” or higher ratings from five of six states. However, most of the “no opinion” answers were for the diamond display, and because of the limited number of states that have used this display, it is difficult to draw conclusions about its effectiveness.

Based on the survey, state DOTs appear to be satisfied with the four-corner and line displays. The four-corner display was rated “effective” or higher by 15 states, while six rated it “marginally effective.” The line received ratings “effective or higher” from 14 states. Alternatively, two states gave “not effective” ratings. The survey generated some interesting results, but the display mode choices made by state DOTs revealed a wide range of opinions. Thus, the importance of ODOT’s research effort was further advanced.

FIELD TRIALS

Experiment Design and Data Collection Procedure

Field trials were conducted at two locations in May 2001. One location was a multi-lane highway five miles west of Salem on Oregon Route 22 (OR 22). This location has two lanes in each direction, with a continuous two-way left turn lane in the median. The shoulders are paved and 3.6 m wide on each side of the highway. The speed limit is 55 mph and average daily traffic is 27,900.

The other test section was six miles south of Monmouth on Oregon Route 99W (OR 99W). This two-lane highway has 3.0 m paved shoulders along each travel lane. The speed limit is 55 mph and average daily traffic is 7,900.

These locations were chosen because ODOT's Research Group had been operating traffic recorders at both sites to collect speed data for another study. A Peek Traffic "TrafiCOMP® III, Model 241 Recorder" at the OR 99W site, and a Peek Traffic "Automatic Data Recorder" (ADR) at the OR 22 site were 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 include:

- 0-40 mph
- 40 - 45 mph
- 45 - 50 mph
- 50 - 55 mph
- 56 - 60 mph
- 60 - 65 mph
- 66 - 70 mph
- 70 - 75 mph
- 75 - 80 mph
- 80 - 150 mph

(If a vehicle is traveling just over the bin upper limit, it will be stored in the next higher bin; e.g.. 40.05 mph will be stored in the 40-45 mph bin.)

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. During this baseline period, no work zones were in place and traffic was in a free-flow condition.

For each test, a temporary work zone was set up in the shoulder. The work zone consisted of two, ¾-ton trucks parked on the shoulder with appropriate signing and coning. The rear vehicle was parked approximately 10 m downstream from the speed recorder. A "Type B" arrow panel was mounted on the rear vehicle. Observers were positioned on an access drive off the roadway approximately 120 m upstream of the arrow panel display. During the entire test period at both sites, traffic was in a free flow condition. Figure 3 shows the layout of the temporary work zone at each location.

The field trials took place on May 15 (OR 22) and May 16, 2001 (OR 99W). The total evaluation time at each site was nine hours, divided into three, three-hour test periods. The first period was from 9:00 A.M. to 12:00 noon; the second was between 12:00 noon and 3:00 P.M.; and the third was a nighttime period from 9:00 P.M. to 12:00 midnight. Morning and afternoon peak hours were avoided to ensure that traffic volumes during each hour of the 3-hour period were about the same. The nighttime period started at 9:00 P.M. because sunset did not occur until 8:35 P.M. To avoid confusion, military time is used in the remainder of this section to denote the hourly time intervals (9:00 a.m. is 0900, . . .1:00 p.m. is 1300, etc.).

For all test periods, each caution mode was displayed continuously for one hour. Traffic volume and speed data were collected, and observers from ODOT's Research Group observed vehicle movements and ensured the arrow panel displays were changed at the beginning of each hour.

OR 22 Field Trials

Field trials at the OR 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. The four-corner was used in the third hour of the morning period. At 1200 the cycle was repeated. For the nighttime period beginning at 2100, the order of displays was changed. The line display was used in the first hour, followed by the four-corner and then the diamond.

The following traffic volume data and speed statistics were determined for each hour:

- Lane Distribution (percentage of vehicles in each lane);

- Average Speed; and
- 85th Percentile Speed.

Lane Distribution

Lane distribution data indicate whether 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.

For each hour of testing, vehicle counts were recorded for the westbound travel lanes. Vehicle counts during the same time periods were also pulled from the 30-day baseline data. Table 1 provides a summary of lane distribution (percent in each travel lane) for the baseline period and the test day. Test day hourly traffic volumes combined for the two westbound lanes are also presented. Traffic volumes were highest during the afternoon and lowest at night.

For every baseline hour, 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%. On the test day, the reverse pattern occurred, with more vehicles traveling in the left than in the right lane. During the two daytime test periods, 58.9 to 61.8% of traffic was in the left lane. At night, the effect was even greater, with hourly distributions of vehicles ranging from 88.7 to 92.7% in the left lane.

Chi-square Testing

To analyze the statistical relationship between the type of arrow panel display mode and lane distribution, a chi-square test for independence was run using the test day lane distributions for each of the three, three-hour periods. The null hypothesis (H_0) is stated as: "*The distribution of vehicles in each lane has the same proportions for each arrow panel display.*" At a 0.05 significance level, the results of the chi square testing are:

Morning period: $\chi^2(2, n=2{,}065) = 1.21$, $p > .05$
Afternoon period: $\chi^2(2, n=2{,}359) = 1.59$, $p > .05$
Nighttime period: $\chi^2(2, n=904) = 3.35$, $p > .05$

Based on the chi-square testing, the null hypothesis is not rejected; for the test day, lane distribution is not dependent on arrow panel display type.

The chi-square testing does not consider the baseline lane distributions and the changes between baseline and test day. For the left lane, the percentage point differences between the baseline and test condition for each hour ranged from 17.9 to 63.8 percentage points. During the nighttime period, the highest percentage difference occurred when the diamond display was operating. Between 2300 and 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.

Speed Data

Average Speeds

Average speeds were calculated from the frequency distributions of the binned speed data. The speed data for the two westbound lanes were combined into one frequency distribution, shown in Table 2 (top). Figure 4 (top) shows the calculated average hourly speeds in the westbound lanes for the test day and the 30-day baseline period.

For each test hour, 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 when the diamond display was used. In the afternoon period, baseline and test day speed differences ranged between 3.19 and 4.11 mph, with the largest reduction occurring when the four-corner display was operating. Reductions in average speed between baseline and test day were much greater during the nighttime period, ranging from 8.52 to 9.70 mph. The highest reduction was observed in the last hour (2300 to 2400) when the diamond display was used.

85th Percentile Speeds

The calculated 85th percentile speeds for OR 22 (shown at the top of Figure 5) exhibited a similar pattern to the average speeds. During the morning and afternoon periods, test day 85th percentile speeds 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 and 1100 when the line display was used. In the afternoon period, the greatest difference (64.29 to 59.92 mph) occurred between 1300 and 1400 when the diamond display was operating. At night, the reductions were much higher, and again, the greatest difference occurred when diamond display was used. The 85th percentile speed for this hour was reduced from 64.48 to 56.42 mph.

Chi-square Testing

To examine the effect of arrow panel display mode on speed during the test day, chi-square tests for independence were performed. The tests were used to determine if a relationship existed between arrow panel display mode and speed. If the two variables are independent, the frequency distribution of the speed data will not depend on the display. The null hypothesis (H_0) is: "*The frequency distribution of speed has the same proportions for each arrow panel display.*" For this test, four of the upper 10 speed bins were collapsed into one bin because of low numbers of vehicles in these bins. Seven speed bins were used to calculate the expected frequencies and chi-square statistic; the upper bin being 65+ mph. The results of the chi-square testing are:

Morning period: $\chi^2(12, n{=}2{,}065) = 8.93$, $p > .05$
Afternoon period: $\chi^2(12, n{=}2{,}259) = 28.13$, $p < .05$
Nighttime period: $\chi^2(12, n{=}904) = 8.52$, $p > .05$

Thus, the null hypothesis *is not* rejected for the morning and nighttime periods, but for the afternoon period, the null hypothesis can be rejected because a statistical relationship exists between the type of arrow panel display and speed.

Why was there a statistical relationship in the afternoon period and not the other two three-hour periods? In looking at the average speeds for each hour in Figure 4, it can be seen that the speeds in the afternoon varied more than in the other two periods. The average speed in the afternoon for the diamond and four-corner displays was 55.51 mph, whereas the average speed for the line display was almost 1 mph greater.

OR 99W Field Trials

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

Speed Data

Average Speed

The frequency distributions of the binned speed data are displayed in Table 2 (bottom). Figure 4 (bottom) shows average speeds for the southbound lane for the test day and baseline period. Average speeds were lower than the corresponding baseline hour, but the reductions were about twice what was exhibited at the OR 22 site. The most likely explanation is that the OR 99W site has only one travel lane in each direction, so vehicles could not move to an adjacent travel lane. Also, the researchers observed that vehicles tended to brake more frequently as they traveled through the work zone.

As seen in Figure 4, average speed reductions in the morning period, varied from 7.57 to 8.89 mph. The greatest reduction occurred when the diamond display was used. In the afternoon, baseline and test day speed differences ranged between 6.68 and 7.67 mph, with the greatest difference also occurring with the diamond display. At night, the diamond was also in use when the highest reduction (22.60 mph) happened.

85th Percentile Speed

For OR 99W, the test day and baseline 85th percentile speeds displayed a similar pattern to the average speed distribution (see Figure 5, bottom). During the morning, 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 when the line display was used. In the afternoon, the speeds for each test day hour were between 6.39 to 6.94 mph lower than the baseline hour, with the greatest reduction (from 62.79 to 55.85 mph) occurring with the diamond display. At night, using the diamond display, the test day 85th percentile speed was 23.35 mph lower than baseline. The line and four-corner displays saw reductions of 15.24 and 14.18 mph respectively.

Chi-square Testing

Chi square tests examined the effects the arrow panel display types had on the speed data frequency distribution. The null hypothesis (H_0) is: "*The frequency distribution of speed has the same proportions for each arrow panel display.*" The upper five speed bins were collapsed into one bin because of low numbers of vehicles, so for the morning and afternoon periods, six speed bins were used to calculate expected frequencies and the chi-square statistic; the upper bin being 60+ mph. Because the nighttime period had lower volumes and speeds, the upper seven bins were collapsed into one, 50+ mph. The results of the chi-square test for each of the three, 3-hour periods are:

Morning period:	$\chi^2(10, n=585) = 8.90$,	$p > .05$
Afternoon period:	$\chi^2(10, n=623) = 11.96$,	$p > .05$
Nighttime period:	$\chi^2(6, n=232) = 7.83$,	$p > .05$

The probability (*p*) of the observed chi-square value is greater than the significance level for each of the three periods and the null hypothesis is not rejected.

Discussion of the Field Trial Data

The field trials demonstrated that vehicles reduced their speeds for the work zones using the three displays. Chi-square testing for independence showed that there was no relationship between arrow panel display mode and speed, except for the afternoon period at the OR 22 site. However, the chi-square testing does not consider the baseline speeds.

In reviewing the differences of test day and baseline data for each morning, afternoon, and nighttime period, the diamond display resulted in the greatest differences compared to the other two displays. On OR 22, the greatest differences in lane distribution and largest reductions in average and 85th percentile speed were almost always experienced when the diamond display was utilized. The OR 99W site confirmed these results.

There are limitations to this field trial data. Because of time and resource constraints, the field trails were limited to two sites and testing at each site was limited to only one day. Multiple tests repeated at each site over the course of several weeks would have been desirable; still, the two days of field trials yield compelling results. To further assess the effectiveness of each display, motorists were surveyed at one of ODOT's rest areas. The survey results are presented in the next section.

SURVEY OF MOTORISTS

Methodology

Motorists were surveyed at an ODOT rest area on along Interstate 5, approximately 15 miles south of Portland. Interviewers from ODOT and the University of Oregon Survey Research Laboratory conducted the survey on May 25, 2001 from 12:00 noon to 10:00 p.m. At the rest area, 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. 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 where led to a point about 30 to 40 m in front of the three arrow panel displays, and asked a series of questions about the displays. At the end of the 10-hour period, 274 surveys had been completed.

Results

Three versions of the survey questionnaire were used. The versions differed only in the first question, which asked the person to look at one of the three flashing signs being displayed on the back of the truck. Approximately one-third of the people surveyed were asked to look at the four-corner display, one-third at the line display, and the remaining one-third 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?" Regardless of display, most people (at least 70%) responded that they would either slow down or proceed with caution. A small percentage (less than 5% for each display) said they didn't know what to do.

The second question asked drivers to look at all three flashing displays. The interviewer explained that the three flashing arrow panel displays were used as a caution warning to alert drivers as they approach a temporary work zone. The interviewer then asked, "Which one of the three flashing signs is most effective in getting your attention?" Of the 274 surveyed, 207 (76%) said the diamond. Forty (15%) choose the line display and 23 (8%) picked the four-corner. Four (1%) people were undecided.

Drivers were asked why they choose a particular display mode. The following is a synopsis of the responses.

- Diamond – alternating pattern, more flashing lights, brighter, looked bigger, it's moving.
- Line – was brighter, stood out more, had more lights on, provided the greatest contrast.
- Four-corner – looked brighter, four separate lights covered a larger area, all four lights flashed.

When asked, "Is one of the three flashing signs easier for you to see?" 218 of the 274 respondents (80%) said yes. The majority felt the diamond display was the easiest to see. The distribution of responses was:

- Diamond – 131 (60%)
- Line – 51 (24%)
- Four-corner – 29 (13%)
- Combination of two displays – 7 (3%)

Those choosing a particular display were asked why was it easier to see the display they chose; the answers were similar to those offered when drivers were asked why one display was most effective.

Then drivers were asked: "Do any of these flashing signs confuse you about what action you should take?" with 168 (61%) answering yes. The 168 respondents were then asked: "Is one (of the three flashing signs) more confusing to you than the others about what action you should take?" In response, 128 said yes, meaning that the 40 people who answered "no" believed that all of the displays were confusing. The 128 who said yes were asked to pick the display(s) that confused them the most. The distribution of answers was:

- Diamond – 15 (12%)
- Line – 48 (37%)
- Four-corner – 46 (36%)
- Combination of two displays – 19 (15%)

The motorists were asked: "Do any of these flashing signs suggest that you change lanes?" Only 78 of 274 respondents said yes. Those who answered yes were asked to identify which display(s) suggested a lane change, with the following distribution of responses:

- Diamond – 55 (71%)
- Line – 15 (19%)
- Four-corner – 3 (4%)
- Combination of two or more displays – 5 (6%)

Drivers were asked to choose one flashing sign they would like to see used when work is taking place on the highways. The distribution of answers from the 274 respondents was:

- Diamond – 219 (80%)
- Line – 25 (9%)
- Four-corner – 24 (9%)
- Combination of two or more displays – 5 (2%)

Motorists were also asked to provide years of driving experience. The average years of driving experience for the 274 participants was 27.7 years, however, the distribution is very dispersed, with a standard deviation of 15.10 and at least five percent of the drivers comprising each of the eleven, 5-year categories (0-5 to 50+). The modal class was 25-30 years. A cross-tabulation table was created to analyze the years of driving experience and the distribution of responses to the question, "Which display is the most effective at getting your attention?" The results showed that for every 5-year increment of experience except one (46-50 years), 70% or more respondents chose the diamond display. Within the 46-50 year category, 8 of 15 (54%) respondents chose the diamond display as the most effective. A chi-square test for independence was also run to see if choice of the most effective display varied with number of years of driving experience. The null hypothesis (H_0) is: "*The distribution of choices for the most effective arrow panel display has the same proportions for each category of driving experience.*" The results of the chi-square testing are:

$$\chi^2(30, n=274) = 40.08, \quad p > .05$$

The probability (p) of the observed chi-square value is greater than the significance level and the null hypothesis is not rejected.

Discussion of Survey Results

The motorist survey showed that driver confusion with the arrow panel displays is high, with 61% (168 of 274) finding the displays confusing. Additionally, 29% (78 of 274) thought that one or more of the displays suggested a lane change, including 55 who felt the diamond suggested a lane change. The data reveal a lack of understanding about the meaning of all three caution modes. Still, the survey results make a case for the use of the diamond display in temporary work zones. This display was chosen by 76% of the respondents (207 of 274) as the most effective in getting their attention and 60% (131 of 218) said the diamond was easier to see.

As with the field trial data, there are also limitations with the survey data. The survey was conducted at a rest area where people could be easily surveyed. Since the rest area is along a major north-south Interstate corridor, both Oregon-licensed drivers and out-of-state drivers were surveyed. Thus, the out-of-state drivers may be less familiar with the diamond display. The survey did not ask people about their familiarity with each of the display modes, so the novelty effect of the displays could not be measured. A different response may also have resulted at a more realistic setting such as an actual work zone.

CONCLUSION

The results of the State DOT survey showed that most states are using the line and four corner displays as an advance warning device in temporary work zones. There was some reported use of the diamond display by six states. From the survey data, there is no one clear preferred display.

The field trials on OR 22 and OR 99W provided noteworthy results. Hourly average and 85th percentile speeds decreased from the 30-day baseline speeds for each arrow panel display mode. Chi-square testing for independence found no statistical relationship between the arrow panel display type and lane and speed distribution except for one three-hour period. In the afternoon period at the OR 22 site, a statistical relationship was found between arrow panel display mode and the speed distribution. In comparing test day to baseline speed data, the greatest reductions in 85th percentile and average speed for most three-hour periods occurred when the diamond display was operating. Further, when comparing test day to baseline, the lane distribution shifts at the OR 22 test site were greatest for all three periods during the hours the diamond display was in use.

The motorist survey conducted at the Interstate 5 rest area demonstrated the usefulness of the diamond display mode as an advance warning device for temporary work zones. Over 70% of those surveyed chose the diamond display as the most effective at getting their attention. However, the majority (61%) of the respondents who were surveyed found the three displays confusing, particularly the line and the four-corner. In addition, about 29% of the 274 surveyed indicated the displays suggested a lane change, including 55 who thought the diamond display meant to change lanes. The large number of respondents who find the displays confusing, or think they mean to change lanes, indicates the lack of understanding about the meaning of the caution displays. Still, 80% of the respondents would like to see the diamond used when work is taking place on Oregon highways.

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

RECOMMENDATIONS

1. Greater emphasis should be given to educating the public about the use of “caution” modes on arrow panel displays.
2. The results of this research should be used to complement similar research being conducted by the Utah DOT.
3. The diamond display should be considered in the future as an alternative to the four-corner and line displays when using caution modes as an advance warning when working on the shoulder or alongside the roadway.

REFERENCES

1. Fortey, N. Federal Highway Administration. Letter to the author, June 8, 2001.
2. 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.
3. 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.
4. Utah Department of Transportation, Division of Research. *Scope of Work: Evaluating the Effectiveness of “Dancing Diamond” Caution Mode as an Early Work Zone Warning Device*. October 18,2000.

List of Tables and Figures

FIGURE 3 Temporary work zone layouts for arrow panel field tests.
FIGURE 4 Average speeds at OR Route 22 and OR Route 99W sites.
FIGURE 5 85^{th} Percentile speeds at OR Route 22 and OR Route 99W sites.

TABLE 1 Lane Distribution - Arrow Panel Display Field Test on OR Route 22 Westbound (WB) Lanes

Time	Time Period	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)*	*(9) = (7)-(8)*
0900 to 1000	Morning	Diamond	653	38.3%	63.5%	61.7%	36.5%	**25.3**
1000 to 1100	Morning	Line	708	40.5%	62.7%	59.5%	37.3%	**22.2**
1100 to 1200	Morning	4-Corner	704	41.1%	61.6%	58.9%	38.4%	**20.6**
1200 to 1300	Afternoon	Diamond	880	38.2%	59.9%	61.8%	40.1%	**21.7**
1300 to 1400	Afternoon	Line	775	40.5%	59.2%	59.5%	40.8%	**18.7**
1400 to 1500	Afternoon	4-Corner	882	40.7%	58.7%	59.3%	41.3%	**17.9**
2100 to 2200	Night	Line	419	11.9%	65.3%	88.1%	34.7%	**53.3**
2200 to 2300	Night	4-Corner	293	11.9%	69.4%	88.1%	30.6%	**57.4**
2300 to 2400	Night	Diamond	192	7.3%	71.1%	92.7%	28.9%	**63.8**

Table 2: Test Day Speed Distribution – Frequency Distribution for Counts of Vehicles Traveling at Speeds Within Each Bin Range

	Time	Time Period	Display	Speed Bins										
				<40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80	>80	Total
OR 22	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
OR 99	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

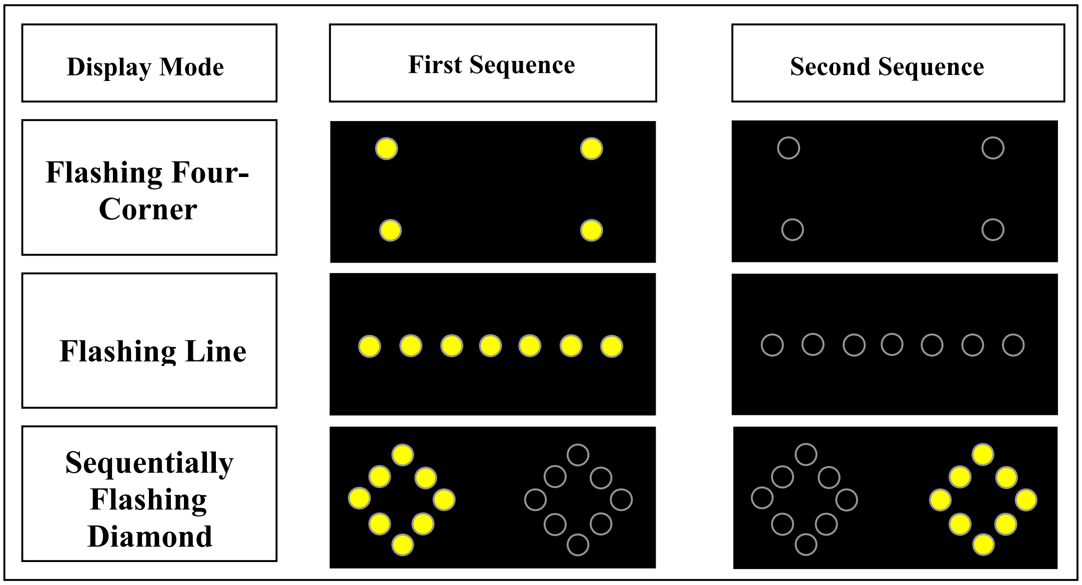


FIGURE 1 Arrow panel display modes used as an advance caution warning.

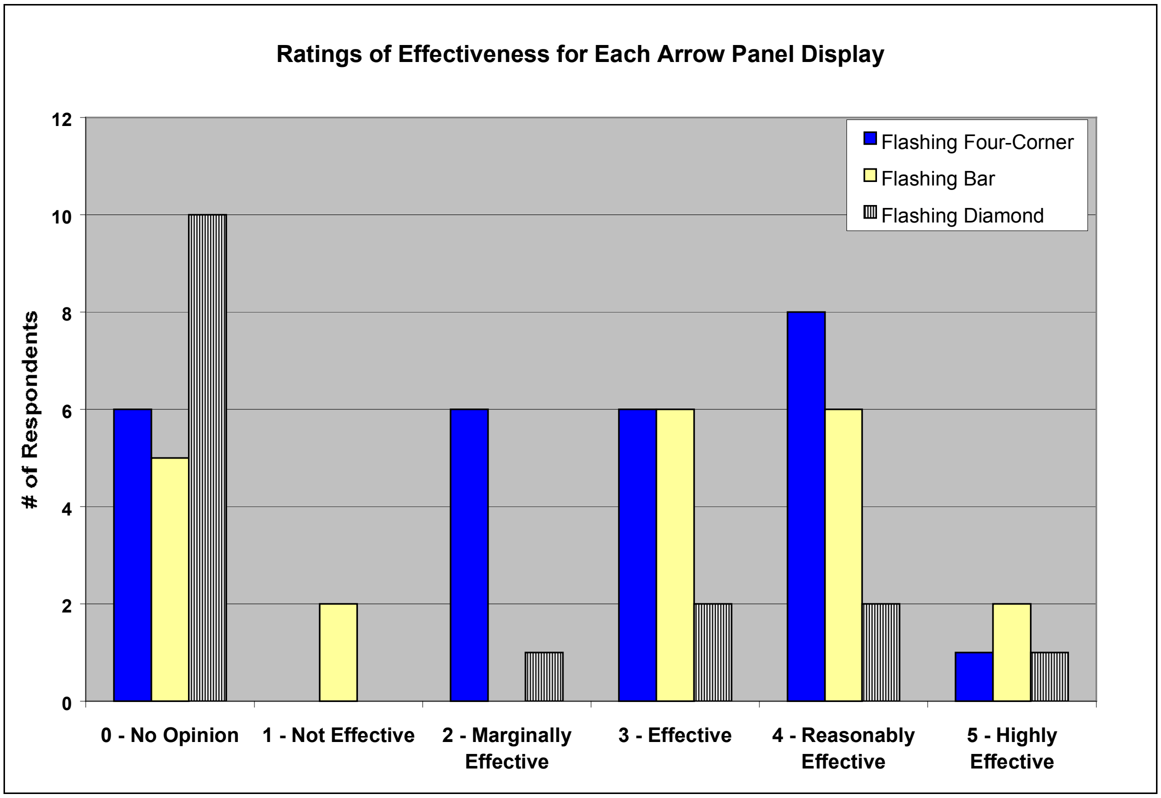


FIGURE 2 Effectiveness of each display mode used as an advance caution warning to drivers.

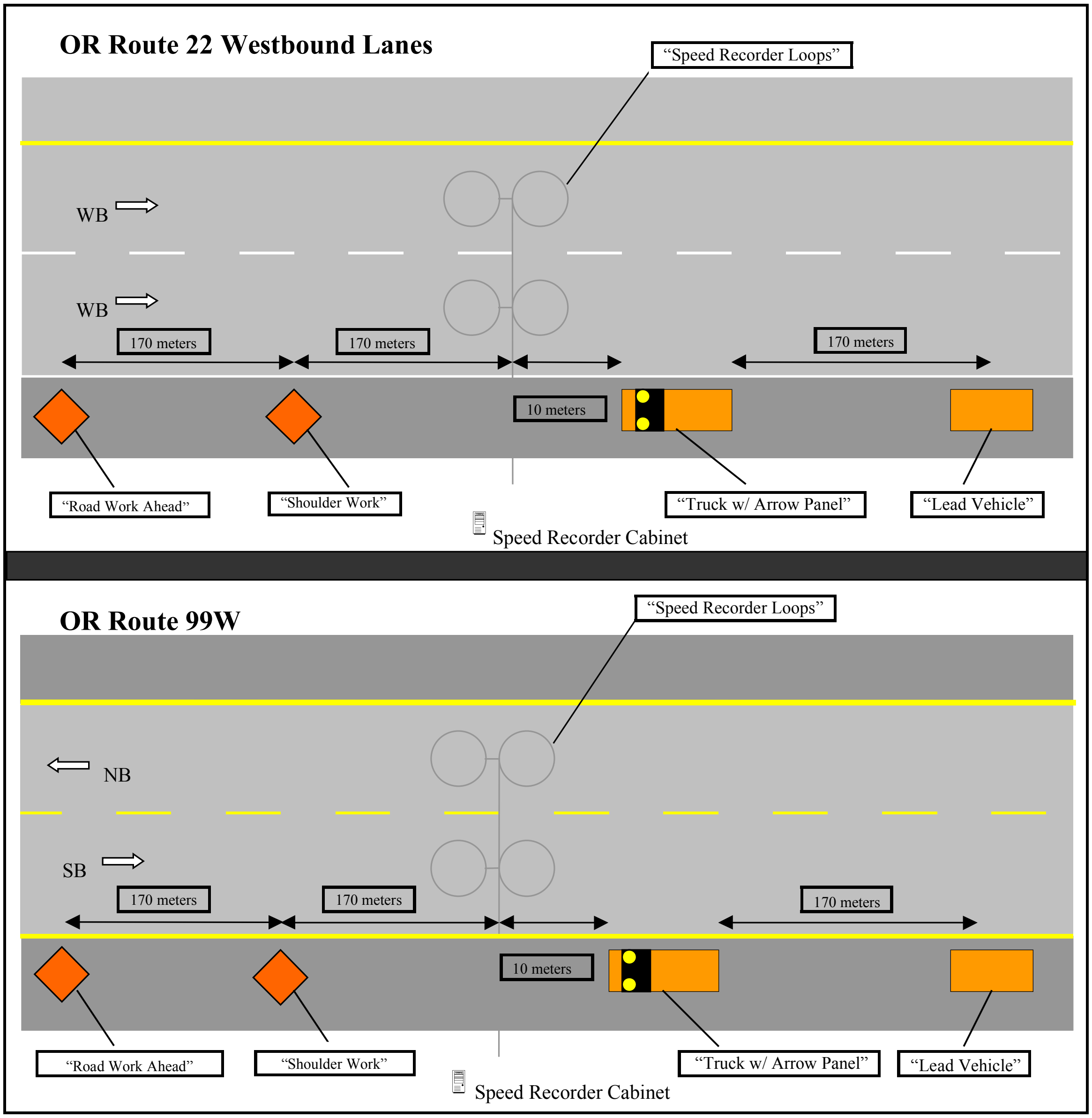
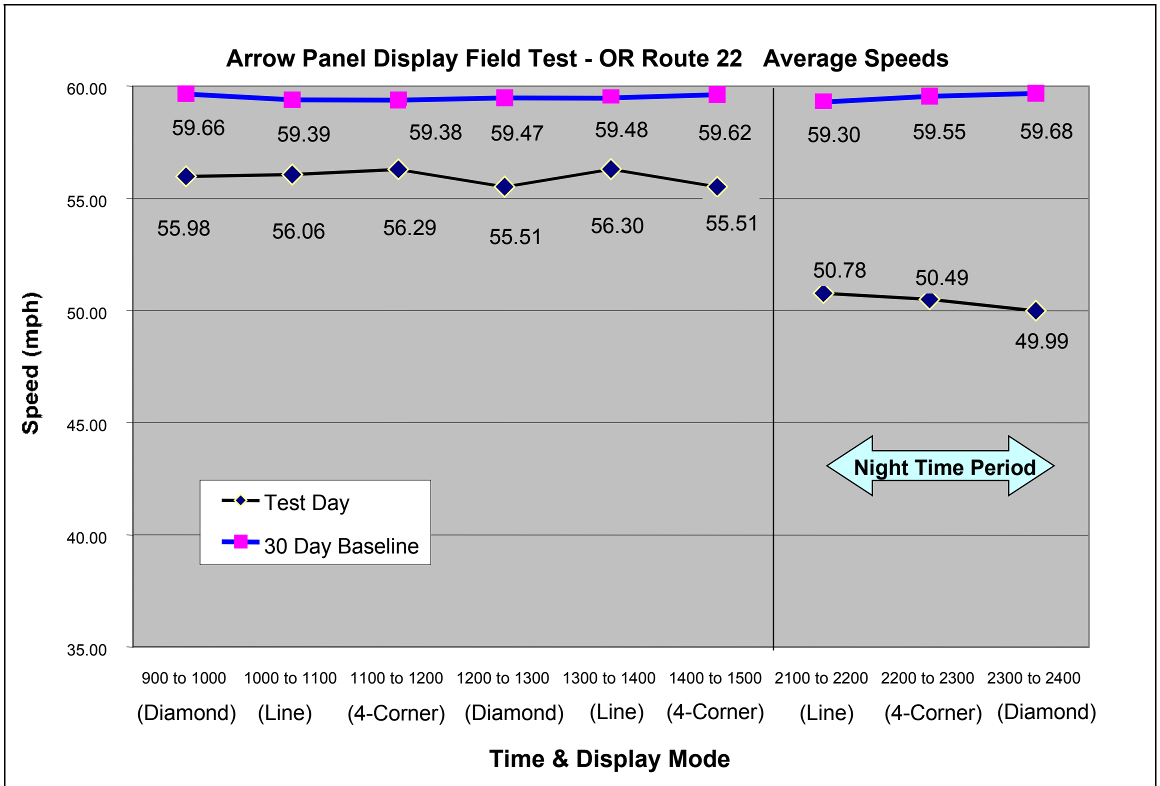


FIGURE 3 Temporary work zone layouts for arrow panel field tests.



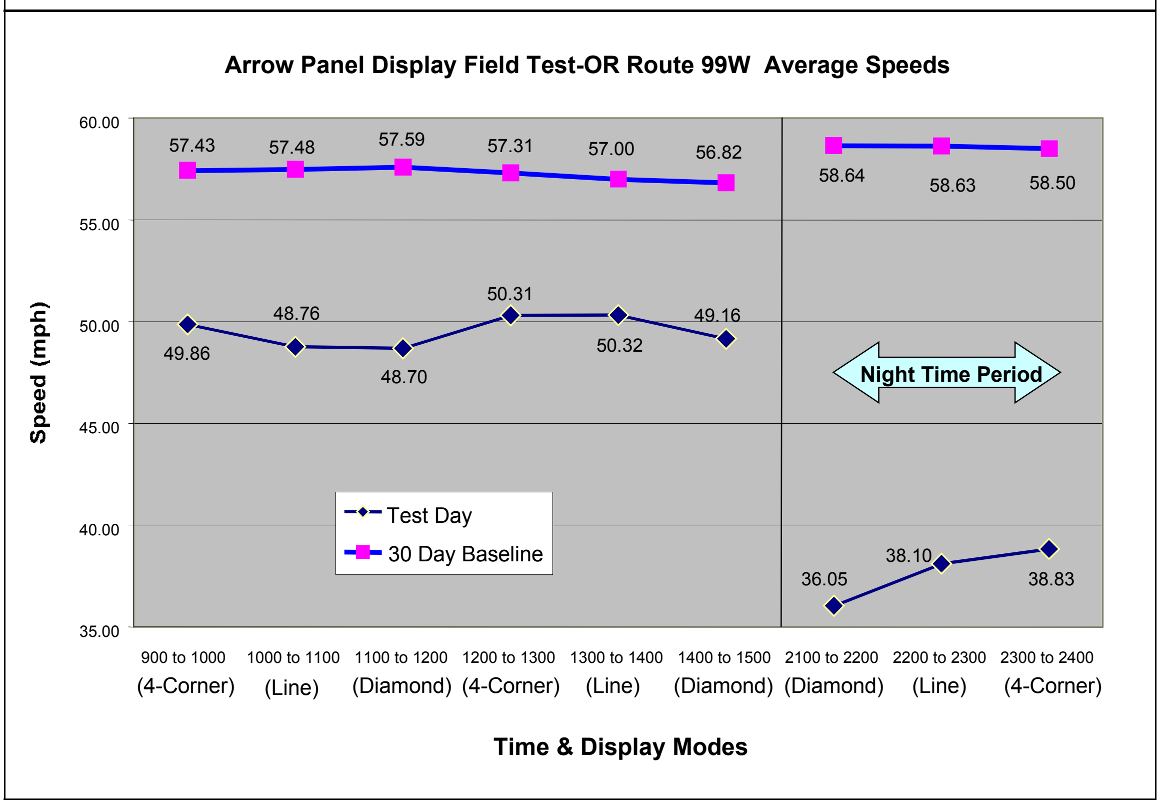


FIGURE 4 Average speeds at OR Route 22 and OR Route 99W sites.

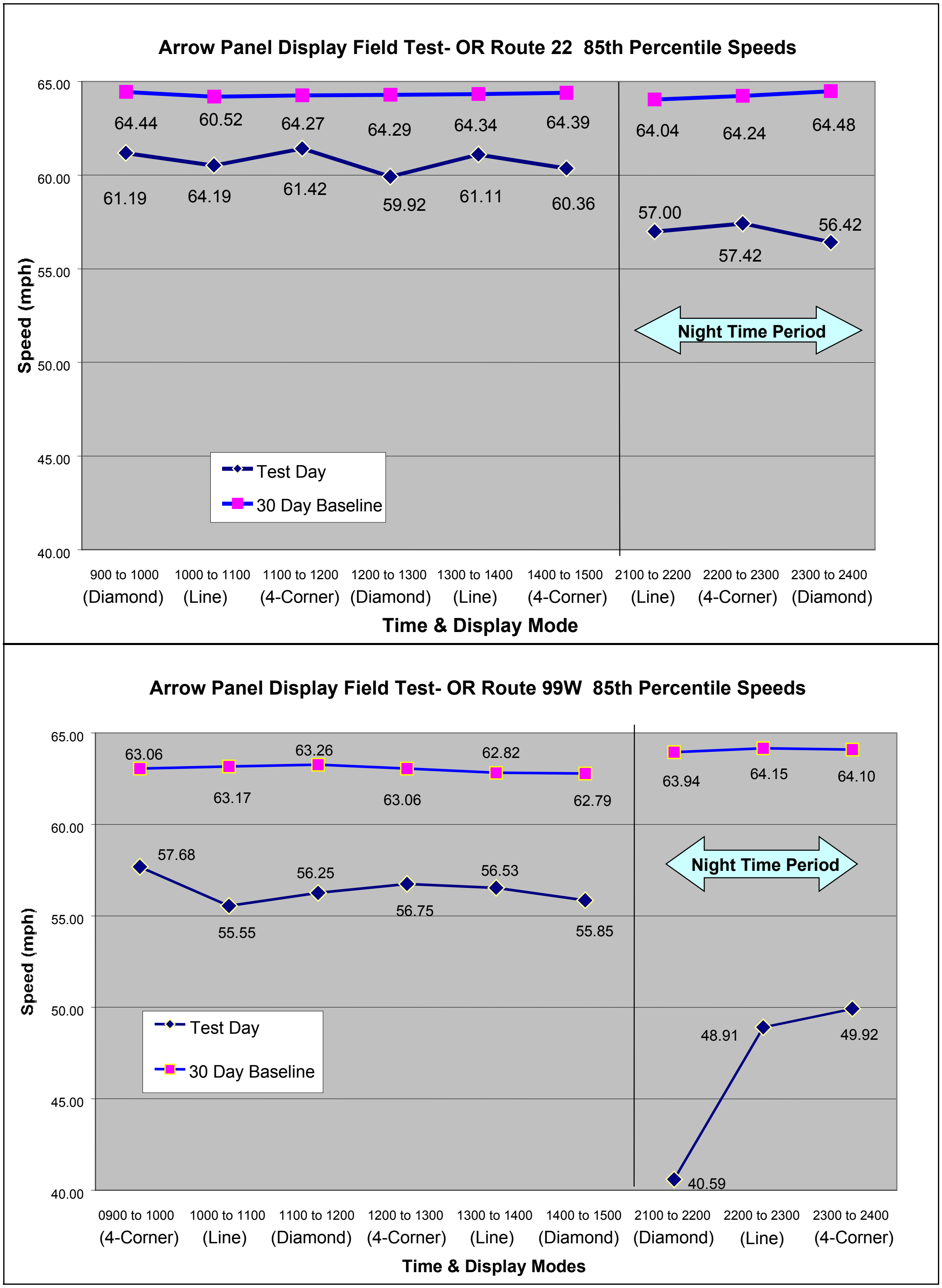


FIGURE 5 85th Percentile speeds at OR Route 22 and OR Route 99W sites.