Dancing Diamonds in Highway Work Zones: An Evaluation of Arrow-Panel Caution Displays

by

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ABSTRACT

Arrow panels, consisting of a matrix of lights, symbolically convey additional warning to motorists. Nondirectional arrow panel displays are designated as caution displays. Before 2001, literature lacked significant statistical support for any one type of caution display. A 2001 Oregon Department of Transportation (ODOT) study suggests that the Dancing Diamonds display performs in the field as well as, if not better than, other caution displays. ODOT also found that local citizens preferred the Dancing Diamonds over other caution displays. However, additional research was needed to confirm these findings.

The Utah Department of Transportation (UDOT) has used the Dancing Diamonds display since June 1972. To evaluate the effectiveness of the Dancing Diamonds and Flashing Box displays a field experiment was conducted. The results of this experiment show that the Dancing Diamonds was associated with a statistically significant 3 kph (2 mph) reduction in mean speeds, whereas the Flashing Box display was associated with no statistically significant reduction in mean speeds, indicating that the Dancing Diamonds prompts safety near highway work than the Flashing Box.

A comprehension/opinion survey was also conducted. Regardless of caution display type, most of the 412 respondents would “slow down” upon seeing any caution display, and they understood the meaning of the display to be “use caution ahead.” Fifty-four percent of drivers thought that use of the Dancing Diamonds would best prompt safe driving, followed by the Flashing Diamonds (43%) and the Flashing Box (3%). For getting attention, 94% said the Flashing Box was the least effective.
DANCING DIAMONDS IN HIGHWAY WORK ZONES: AN EVALUATION OF ARROW PANEL CAUTION DISPLAYS

INTRODUCTION

Arrow panels have been widely used in highway work zones for the past twenty-five years. These panels are signs consisting of a matrix of lights that convey additional warning and direction symbolically to motorists. This matrix of lights is capable of flashing directional displays as well as nondirectional displays. Directional displays, such as “Flashing Arrow” and “Sequential Chevron,” have been effectively used to aid drivers in switching lanes. Directional guidance is the main purpose of arrow panels. However, to maximize safety per dollar of investment, a nondirectional “caution” display has also been used. This caution display is the only nondirectional arrow panel display authorized by the current Manual on Uniform Traffic Control Devices (MUTCD) and is designated “Flashing Caution” (1).

The purpose of the caution display is to increase safety near highway work. Caution displays provide additional warning to drivers, so that they may exercise caution while traveling through an upcoming work zone. Safely slowing down, switching lanes on a multilane highway, and being more alert are all acceptable forms of exercising caution. The caution display is currently designated for shoulder work operations and lane closures on a two-lane, two-way highway (1). Unlike all other arrow panel displays, the caution mode never requires the driver to make a lane change. Even when used at a temporarily closed lane of a two-lane, two-way highway, the caution display is meant only to alert the driver and to call attention to the other traffic-control devices.

Figure 1 shows the various caution display types. Before the MUTCD 2000 edition, the Flashing Box and Bar were suggested, but any “caution mode consist[ing] of four or more lamps” which “did not indicate a direction” was permitted (2). The Flashing Box and Bar have been used throughout the United States. The Dancing Diamonds pattern has been used in the western states, such as Utah and Oregon. The Utah Department of Transportation (UDOT) has used the Dancing Diamonds display since June 1972 on state funded projects. The Alternating Two-Corner display has been studied in the past, but to the authors’ knowledge has not been used. The Flashing Diamonds pattern was proposed recently by the Utah Department of Transportation (UDOT).

The main purpose of this research is to evaluate the effectiveness of the Dancing Diamonds caution display as compared with the standard Flashing Box caution display. A brief literature review was first performed. Second, a field experiment was conducted to gather actual driver responses to caution displays. Third, a
comprehension/opinion survey was conducted to measure driver comprehension of caution displays as well as
gather opinions concerning caution displays. At UDOT’s request, consideration for the Flashing Diamonds was
added midway through this research and, consequently, is analyzed in the comprehension/opinion survey only.
These three areas of research are discussed in the paper. The study yielded the following conclusions: (1) there was
insufficient past research on which to base caution displays standards; (2) the Dancing Diamonds display was
associated with cautious driving, whereas the Flashing Box display seems to have little effect on drivers; (3) there
was little difference in driver comprehension between the Dancing Diamonds, Flashing Diamonds, and Flashing
Box displays; however, a majority of respondents felt that the Dancing Diamonds display best prompted safety near
highway work.

LITERATURE REVIEW

Non-directional caution displays have not been studied exclusively until recently. This review first focuses on past
research, which is the foundation for current standards. In past research, caution displays were appendages to
broader research on directional displays. Consequently, only the caution display segments of that research were
examined. Second, this review looked at recent Oregon Department of Transportation (ODOT) research (3), which
focuses specifically on caution displays. ODOT’s research and evidence suggested that some caution display types
were more effective than others.

Past Research

A December 1978 Federal Highway Administration (FHWA) report consists of two separate studies: a human
factors study and a field study (4). This study is accompanied by a set of recommendations.

Human Factors Study

The authors of this study, Knapp et al., also published these findings separately in the Transportation Research
Record (5). The authors created a series of film clips of different arrow display types (directional and
nondirectional). This film was shown to twenty respondents as they answered multiple choice questions. From the
results of the survey, Knapp et al. suggest that nondirectional displays or mere blinking lights, “stirred more
confusion than they aroused meaning” (5). However, speaking of the survey, the authors confess that their “film
efforts, sample size, and composition were limited and unrefined.” Thus they recommend a much more detailed
investigation of nondirectional arrow-board displays.
Field Study

Graham et al., the principal authors of the 1978 FHWA report, conducted extensive arrow panel field research using actual work zones. However, only five maintenance shoulder closures were relevant to this discussion. One work zone used the Bar type of caution display. Two work zones had “Flashing Arrow” (directional) displays. The other two zones had no arrow panel displays.

Research data were collected for one hour or less at each test location. A researcher stood in the back of the maintenance trucks and filmed oncoming traffic. The equipment used was a 16 mm camera with time-lapse photography. Based on these testing techniques, Graham et al. concluded that “slow-vehicle conflicts [when a vehicle swerves or brakes to avoid a slower vehicle in front] are increased when the [Bar display] is used” (4).

In Appendix B of the 1978 FHWA report, Graham et al. offer guidelines for arrow-board use. Using the results from both the human factors study and their field study, they recommend the following: “All other arrow board modes such as…non-directional displays should not be used for construction and maintenance activities.”

ODOT Caution Display Research

Field Tests

ODOT’s research tested two temporary highway work-zone locations for one day at each. At both locations, the Flashing Box, Bar, and Dancing Diamonds were used at various hours during the test. The researchers concluded, based on lane distributions and speed information, that “the [Dancing Diamonds] display performed as well [as], if not better than, the [Bar] or [Flashing Box] displays” (3).

Comprehension/Opinion Survey

ODOT surveyed 274 drivers at highway rest areas. Three arrow board trucks were set up to show the Flashing Box, Bar, and Dancing Diamonds for the survey. The majority of drivers (61%) found one or more of the signs confusing. However, 75% chose Dancing Diamonds as the “most effective at getting their attention.” Eighty percent preferred the Dancing Diamonds for use on Oregon highways.

DESIGN OF EXPERIMENTS

Two statistical methods of analysis were used in this study to determine which caution display patterns were most effective. First, a randomized field experiment was conducted to measure the reactions of the driving public to two
different caution displays. Second, an opinion survey was given to measure driver knowledge of and preferences for caution displays.

Field Experiment Design

The goal of the field experiment was to collect quantifiable data that measured the effectiveness of the Dancing Diamonds and Flashing Box caution displays. Using MUTCD standards, a general layout was created (see Figure 2). This layout shows a typical shoulder work zone where a truck-mounted caution display is used. Speed reduction, lane migration, and conflict characteristics were collected for two days (a week apart, one day for each display type) at each of the 24 Utah test sites shown in Figures 3. In order to conduct tests at 24 sites in a three-month period mock-up shoulder work zones were used for set up. Two workers who set up traffic control devices for a test site remained at the site during the data collection to pretend as workers. There was no actual work underway in these mock-up work zones.

Speed data were collected in the right-most lane closest to the shoulder work zone (see Figure 2 for speed data collection locations) during off-peak hours, both during the day and at night to avoid the confounded effect of the level of volume on speed. See the notes section of Table 1a for the time of the day when speed data were collected. The order of placing the Dancing Diamonds and the Flashing Box displays was randomly determined. Speed limits were either 65 or 55 mph at the urban highway sites and 55 mph at the rural highway sites. Refer to reference (6) for the detailed discussions of the field data collection design.

Speed Reduction

This criterion measured which caution display caused the greatest speed reduction, if any. To measure speed reductions, a pair of pneumatic tubes (7) was placed to record speeds at three locations (refer to Figures 2):

- A “Free Flow” location (FF) where speed should not yet be affected by temporary signs, arrow board, and the work zone.
- A “Sign 1” location (S1) where the driver has read “ROAD WORK AHEAD” and can legibly see the arrow board display in the distance.
- An “Arrow Board” location (AB) where the driver actually passes the arrow board and encounters “friction” with channelization barrels.

The abbreviations FF, S1 and AB are used in the subsequent discussions in the paper.
Lane Migration

Actual traffic was examined for lane-migration characteristics. With the aid of the UDOT Traffic Operations Center, urban locations were videotaped using Closed Circuit Television (CCTV) cameras used for the Salt Lake City metro area Advance Traffic Management System (ATMS). After the sites were videotaped, the videos were examined to count the percentage of vehicles safely leaving the right lane. For urban (multi-lane) roadways, migration from the right lane to the adjacent lane is desirable because it creates additional buffer space between drivers and highway workers. For rural (two-lane, two-way) locations, an observer in a van logged any unsafe lane migration. Obviously, lane migration is and unsafe and undesirable maneuver for two-lane, two-way facilities.

Conflicts

Again using video for urban locations and an observer for rural locations, any unsafe vehicle conflicts were cataloged. This was done by counting brake-lights (potential hard braking) and by subjectively judging and tabulating any unsafe maneuvers that might have been attributed to the presence of the arrow board displays.

Comprehension/Opinion Survey Design

The goal of this comprehension/opinion survey was to collect quantifiable public opinions about the effectiveness of the Dancing Diamonds (DD), Flashing Box (FB), and Flashing Diamonds (FD) caution displays (see Figure 1). We wanted to know what drivers think each caution display means and which of the three displays they preferred. After one pilot survey, we finalized a one-page survey with nine multiple-choice and fill-in-the-blank questions. The actual survey is shown in Figure 4, and is explained below. Surveys were conducted at two Utah Visitor Centers, a gas station, a Division of Motor Vehicle office, a downtown Salt Lake City mall, and a suburban mall. The term “Alternating Diamonds” instead of Dancing Diamonds was used in the survey to avoid bias toward the Dancing Diamonds display. Survey participants were rewarded with large-size candy bars.

Comprehension Questions

Questions #1 and #2 consider what drivers think a particular caution display means. For these first two questions, each respondent sees only one of the three caution display types. Thus, approximately one-third of the total respondents will answer comprehension questions about each display.
Question #1 “In this situation, your first reaction would be to…” is asked verbally while the respondent looks at a short video segment. The video shows a driver’s perspective while driving down a highway. A work zone with a caution display (Dancing Diamonds, Flashing Diamonds, or Flashing Box) appears on the right shoulder. The respondent then chooses one of the multiple-choice answers as his or her first reaction (see Figure 4 for the selections).

Question #2 “What does this sign mean to you?” is also asked verbally while the respondent looks at another short video segment. This video is simply a close-up of the sign the respondent saw in Question #1. The respondent then chooses one of the multiple-choice answers as the meaning of the sign (see Figure 4 for the selections).

Opinion Questions
Questions #3 and #4 gather opinions about each caution display. Each question is asked verbally while the respondent looks at all three caution display videos simultaneously.

Question #3 “In your opinion, which of these three signs would best prompt safe driving near highway work?” The respondent then chooses one of the multiple-choice answers: “Flashing Box,” “Alternating Diamonds,” or “Flashing Diamonds.” (Note that the name “Alternating Diamonds” was used in this survey to avoid any “dancing” bias.)

Question #4 “In your opinion, which of these three signs would most likely be ignored?” The respondent then chooses one of the multiple-choice answers: “Flashing Box,” “Alternating Diamonds,” “Flashing Diamonds,” or “None of them.”

Demographic Questions
Questions #5, #6, #7, #8, and #9 gather characteristics of the driver sample. This helps determine if different segments of the driver sample have different perceptions or opinions about caution displays.

FINDINGS FROM THE FIELD EXPERIMENTS
Data were collected between July 17, 2001 and September 19, 2001 at locations shown in Figure 3. See reference (6) for the data availability at these locations and the detailed discussions of the statistical analyses. The speed reduction analysis shows that the Dancing Diamonds display was found to lower mean speeds by approximately 3 kph (2 mph), while the Flashing Box display showed no significant speed reduction. Lane migrations and conflict observations yielded virtually no noticeable unsafe or erratic movements affiliated with either display type.
Speed Reduction

Using SAS statistical analysis software (8), speed data were analyzed to yield a generalized linear model (GLM) using weighted least-squares. The model was weighted by the number of cars used to obtain the average speeds. Average speed was the response variable. Explanatory variables, such as Type and Time, are shown in Table 1a. A blocking variable (Loc(Loctype)) was also used to correctly analyze the differences in each site (i.e., between week 1 and week 2).

Through a process of insignificant variable elimination, the “full” GLM was simplified to a better fitting “reduced” GLM (shown in Table 1b). Through successive iterations, variables or terms were removed based on their significance value, called a p-value. If the p-value was above 0.10, then we are confident that the variable was insignificant. Because of the more complex nature of interaction terms, a 0.20 cutoff was adopted for them. Table 2 shows a list of variables that were excluded in the final model because their coefficients were not statistically significant. This table shows why certain variables did not make it into the final model. For instance, the LocType*where interaction variable in Table 3 was not significant, meaning that the effect of speed reduction was the same for both urban and rural locations.

The final model had an R-squared term of 0.85, meaning that it fit the speed data well. The mathematical equation associated with this model is:

\[
\text{Speed}[\text{mph}] = 62.0 - (4.7 \text{LocType}_{\text{Rural}}) - (1.1 \text{Order}_{1}) + (1.2 \text{Time}_{\text{Day}}) + (3.7 \text{Type}_{\text{BX}}) \\
+ (1.8 \text{Where}_{\text{FF}}) + (1.4 \text{Where}_{\text{S1}}) - (1.9 \text{LocType}_{\text{Rural}} * \text{Type}_{\text{BX}}) + (1.6 \text{Order}_{1} * \text{Where}_{\text{FF}}) \\
- (1.0 \text{Order}_{1} * \text{Where}_{\text{S1}}) - (1.2 \text{Time}_{\text{Day}} * \text{Type}_{\text{BX}}) + B_{\text{Loc(Loctype)}}
\]

where \(B_{\text{Loc(Loctype)}}\) is the blocking variable linear function with 20 additional coefficients for each site. Please note that by using the blocking variable and weighted least-squares, ones and zeros cannot be simply inserted into this equation to obtain speeds. Expected speed values for these various conditions can only be calculated using statistical software.

Using SAS statistical software, expected mean speed values were obtained and plotted. These plotted points were compared with each other using t-tests to obtain individual p-values that show any significant differences (i.e., p-values < 0.10).
Speed Reduction for Flashing Box vs. Dancing Diamonds

Figure 5 shows the plot of expected mean speeds from this GLM. The Flashing Box speeds have no statistically significant difference among themselves:

- Box (Free Flow) vs. Box (Sign 1) has a p-value of 0.99;
- Box (Sign 1) vs. Box (Arrow Board) has a p-value of 0.78;
- Box (Free Flow) vs. Box (Arrow Board) has a p-value of 0.75;

This shows no statistically significant speed reduction associated with the Flashing Box caution display.

The Dancing Diamonds speeds, however, do show a statistically significant difference among themselves:

- Diamonds (Free Flow) vs. Diamonds (Sign 1) has a p-value of 0.01;
- Diamonds (Sign 1) vs. Diamonds (Arrow Board) has a p-value of 0.08;
- Diamonds (Free Flow) vs. Diamonds (Arrow Board) has a p-value of < 0.01;

This shows a statistically significant speed reduction associated with the Dancing Diamonds caution display. The average reduction is approximately 3 kph (2 mph). This small but statistically significant difference is important because the caution displays are meant for warning the drivers and attracting their attention; they are not meant for causing a substantial speed reduction.

This graph also yields statistical comparisons between the Flashing Box and Dancing Diamonds displays. The Free Flow speeds were not significantly different (p-value = 0.36). This validates our assumption that the Free Flow speeds should not have been affected by the caution displays. The Sign 1 and Arrow Board speeds were significantly different (p-value = 0.09 and < 0.01, respectively).

Speed Reduction for Week 1 vs. Week 2

Figure 5 also shows that the signs’ effect on speed reduction diminishes over time. During the first week, speeds as a whole dropped more significantly than they did during the second week. Most likely a novel effect of the displays wore off in the second week.

- Week 1 (Free Flow) vs. Week 1 (Arrow Board) has a p-value of < 0.01;
- Week 2 (Free Flow) vs. Week 2 (Arrow Board) has a p-value of 0.43;
Lane Migration

Lane migration was based on visual data collection. Unfortunately, due to logistical problems, only three urban sites had video for both the Dancing Diamonds and the Flashing Box test periods. No statistically significant results could be obtained, though preliminary analysis (using the little data collected) indicates no difference between the two caution displays. For rural sites, lane migration was noticed only when there was no opposing traffic, and channelization barrels were very near the travel lane. No unsafe lane migration was associated with either caution display.

Conflicts

Conflict analysis was a subjective measure of effectiveness used to notice any repeated unsafe driving in connection with the work zones. However, very little unsafe driving or hard-braking was noticed in connection with the work zone and caution displays.

Yet, in an effort for quantifiable analysis, any brake tapping was tabulated. Again there were insufficient data to infer any statistically significant conclusions for urban data. Notwithstanding, preliminary analysis shows little difference between sign types. Rural data were sufficient and were analyzed using ANOVA (6). Even after taking into account time of day and the order in which sign types were shown, there was no significant difference in the number of people braking in both sign types (Dancing Diamonds vs. Flashing Box).

FINDINGS FROM THE COMPREHENSION/OPINION SURVEY

A total of 412 surveys were administered. There was little difference in driver comprehension between the Dancing Diamonds, Flashing Diamonds, and Flashing Box displays. A plurality of respondents (46%-55%) would “Slow down” on seeing the caution display, and a majority (55%- 67%) think the signs mean “Use caution ahead.” When asked which caution display best prompts safe driving, 54% chose Dancing Diamonds, 43% chose Flashing Diamonds, and only 3% chose Flashing Box.

Comprehension Questions

Each caution display (Dancing Diamonds, Flashing Diamonds, and Flashing Box) was shown in Questions #1 and #2 to one-third of the total respondents. Although respondents saw different caution displays, there was little
difference in driver comprehension among the Dancing Diamonds, Flashing Diamonds, and Flashing Box displays (see Tables 4a and 4b).

Question #1

When asked what their first reaction would be on seeing a particular caution display, drivers reacted cautiously by slowing down (46%-55%), switching lanes (26%-29%), paying more attention (10-15%), or looking for highway work (3%-5%). However, “Pay more attention” is technically the most correct answer. After applying a chi-square test to see if any response differed significantly between caution displays, only “Continue normal driving” did (p-value = 0.009). This means that Flashing Diamonds are significantly less likely to be ignored relative to the other displays. This may be related to the fact that Flashing Diamonds have never been used in practice, so some people have not “learned” to ignore it.

Question #2

After seeing a close-up view of the sign, the majority of respondents correctly identified a caution display’s meaning: 55%-67% chose “Use caution ahead.” Again, a chi-square test was applied to see if any response differed significantly among caution displays. Only “Do not know” did (p-value = 0.026); significantly more respondents were confused by the Flashing Box display. Finally, quite a few respondents verbally commented that they thought the signs were malfunctioning. Others merely guessed that blinking lights mean caution.

Opinion Questions

Respondents looked at all three caution displays simultaneously, then answered Questions #3 and #4 (See Tables 3c and 3d).

Question #3

Question #3 asked, “In your opinion, which of these three signs would best prompt safe driving?” An overwhelming majority chose a diamond display (97%) over the Flashing Box display (3%). The Dancing Diamonds pattern was favored most (54%) closely followed by the Flashing Diamonds (43%). Some respondents verbally commented that the side-to-side nature of the Dancing Diamonds “catches the eye” better than mere flashing. Others commented, “the more lights—the better,” and chose the Flashing Diamonds.
Question #4

This question “In your opinion, which of these three signs would most likely be ignored?” may be more accurately translated as “Which of these three signs is least effective at getting attention?” Nearly all the respondents chose the Flashing Box (94%). It should also be noted that a fourth option, “None of them,” was also available and was a response only 4% of the time.

Demographic Questions

The purpose of demographic questions is to see if a good cross-section of the driving population has been surveyed.

Questions #5 and #6

Males accounted for 62% of the respondents and females accounted for 38%. Those numbers, along with the age distribution, seem reasonable for a sample of the driving population (see Table 3e).

Question #7

The average time spent driving during a typical workday is 2.4 hours. However, the median time is only 1.5 hours. Several truck drivers driving 10+ hours skewed the average.

Questions #8 and #9

Obviously, Utah was the most common state listed due to the location of the survey, but 28% of the respondents had more driving experience outside Utah. This 28% represents 117 people from 24 states besides Utah. California drivers accounted for the plurality (34) of the 117 drivers. Question #9 (county information) was going to be used to determine urban vs. rural experience in Utah. However, it became apparent that urban vs. rural experience could not be determined simply by county, and the information was therefore not included in this analysis.

Statistical Relationships

To see the robustness of the answers given in Question #3 (Which display best prompts safe driving?), we conducted chi-square tests between Question #3 answers and the following:

1. Which caution display the respondent saw in Question #1 and #2
2. Those respondents who had more driving experience, or in other words, greater than the median 1.5 hours per workday
3. Those with more driving experience outside Utah

4. Gender

The chi-square results show no difference in the answers for Question #3 and each of the relationships listed above (p-values = 0.44, 0.90, 0.82, 0.38, respectively, for the above 4 factors). Therefore, respondents chose Dancing Diamonds regardless of the first display type shown to them, driving experience, or gender.

Some attention was given to the idea that drivers might confuse specific caution display types with directional displays. Respondents who chose “switching lanes” or “lane closure ahead” may have thought the display was a directional display. Again, chi-square tests were applied between the sign type seen in the first two questions and the answers, “switch lanes if possible” and “lane closure ahead,” and showed no significant difference (p-value 0.87 and 0.44, respectively). Therefore, these respondents reacted to the arrow board itself and not the flashing light configuration.

CONCLUSIONS

Before 2001, literature lacked significant statistical support for any one type of caution display. Consequently, caution display standards have been set using professional judgment only. A 2001 ODOT study suggests that the Dancing Diamonds display performs in the field as well as, if not better than, other caution displays. ODOT also found that local citizens preferred the Dancing Diamonds over other caution displays. However, additional research was needed to confirm their findings.

This field experiment was conducted to obtain statistically significant evaluations for caution displays. The results of this field experiment show that the Dancing Diamonds display is associated with a statistically significant 3 kph (2 mph) reduction in mean speeds, whereas the Flashing Box display is associated with no statistically significant reduction in mean speeds. The small but statistically significant difference is important because the caution displays are meant for warning the drivers and alerting their attention and not for requesting a substantial speed reduction. No unsafe lane migration or conflicts were associated with either caution display.

Regardless of caution display type, most of the 412 survey respondents would “slow down” on seeing any caution display, and they understood the meaning to be “use caution ahead.” A majority of drivers (54%) thought that the Dancing Diamonds would best prompt safe driving, followed by the Flashing Diamonds (43%) and the Flashing Box (3%). At getting attention, 94% said the Flashing Box was the least effective.
This paper confirms ODOT’s findings of the superiority of the Dancing Diamonds display over the Flashing Box display. The Dancing Diamonds display causes drivers to slow down cautiously, and is considered by drivers to be better at promoting safe driving near highway work. The Flashing Box display has little effect on driving near highway work, and is considered less effective by the driving population.

RECOMMENDATIONS

It is recommended that the Dancing Diamonds caution display be allowed in the MUTCD. Though the Flashing Box appears to be ineffectual, further studies should validate this before prohibiting its use. Further field tests are also needed to determine the effectiveness of the Flashing Diamonds and Bar displays. Research should also be done to determine if side-to-side lights, such as those used in railroad beacons, school zone beacons, and the Dancing Diamonds display, are better at catching the attention of the driver.

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REFERENCES


7. Speed data collected using *TimeMark Delta IIIIB* traffic counters. Raw data was then analyzed with *TimeMark* software (*TMWin32* version 3.3.0) to obtain vehicle speeds.

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FIGURE 2 Typical field experiment layout.

FIGURE 3 Field test locations.

FIGURE 4 Comprehension/opinion survey form.

FIGURE 5 Speed reduction plots.
TABLE 1 Variables used in the model.

### a) Speed data structure

<table>
<thead>
<tr>
<th>Where</th>
<th>LocType</th>
<th>Loc</th>
<th>Order</th>
<th>Day</th>
<th>Time</th>
<th>Type</th>
<th>AvgSpeed</th>
<th>N</th>
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<tr>
<td>(FF, S1, or AB)</td>
<td>Urban or Rural</td>
<td>(1,2,…, or 22)</td>
<td>(1 or 2)</td>
<td>(Tue, Wed, or Thu)</td>
<td>(Day or Night)</td>
<td>(DD, BX)</td>
<td>Speed in mph</td>
<td>Number of Speeds Recorded</td>
</tr>
</tbody>
</table>

Note:  
- a. FF = Free flow speed location, S1 = Sign 1 location, AB = Arrow board location  
- b. 1 = First week, 2 = Second week  
- c. Day: 10 am – noon for urban and rural test sites. Night: 4 am – 5 am for urban test sites and 9 pm – 11 pm for rural test sites.  
- d. DD = Dancing Diamonds, BX = Flashing Box

### b) Significant variables and variable combinations included in the final model.

<table>
<thead>
<tr>
<th>Variable</th>
<th>P-value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
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<td>Average urban speeds and average rural speeds are different.</td>
</tr>
<tr>
<td>Order</td>
<td>0.007</td>
<td>Average speeds during the first week are different from those during the second week.</td>
</tr>
<tr>
<td>Time</td>
<td>0.158</td>
<td>Needed for the interaction term Time*Type below.</td>
</tr>
<tr>
<td>Type</td>
<td>0.043</td>
<td>Average speeds for the Flashing Box display are different from those for the Dancing Diamonds display.</td>
</tr>
<tr>
<td>where</td>
<td>0.007</td>
<td>The average speeds for the Free Flow, Sign 1, and Arrow Board locations are different.</td>
</tr>
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<td>LocType*Type</td>
<td>0.016</td>
<td>The effect of caution display is different for both urban and rural locations.</td>
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<tr>
<td>Order*where</td>
<td>0.007</td>
<td>The effect of speed reduction is different between the first week speeds and the second week speeds.</td>
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<tr>
<td>Type*where</td>
<td>0.003</td>
<td>The effect of speed reduction is different between Flashing Box and Dancing Diamonds displays.</td>
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<td>Time*Type</td>
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<td>The effect of day vs. night is different between Flashing Box and Dancing Diamonds displays.</td>
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<td>Blocking variable. Used to compare data differences within each test site.</td>
</tr>
</tbody>
</table>
### TABLE 2 Table of insignificant variables not included in the final model.

<table>
<thead>
<tr>
<th>Order Removed</th>
<th>Variable</th>
<th>P-value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LocType*where</td>
<td>0.876</td>
<td>The effect of speed reduction is the same for both urban and rural locations.</td>
</tr>
<tr>
<td>2</td>
<td>Order*Time</td>
<td>0.757</td>
<td>The effect on average speeds for day and night is the same, whether it was the first or second week.</td>
</tr>
<tr>
<td>3</td>
<td>LocType*Order</td>
<td>0.599</td>
<td>The effect on average speeds between the first and second week is the same for both urban and rural locations.</td>
</tr>
<tr>
<td>4</td>
<td>LocType*Time</td>
<td>0.592</td>
<td>The effect on average speeds for day vs. night is the same for both urban and rural locations.</td>
</tr>
<tr>
<td>5</td>
<td>LocType*Day</td>
<td>0.386</td>
<td>The effect on average speeds for day of the week is the same for both urban and rural locations.</td>
</tr>
<tr>
<td>6</td>
<td>Time*where</td>
<td>0.272</td>
<td>The effect of speed reduction is the same for both day and night times.</td>
</tr>
<tr>
<td>7</td>
<td>Day</td>
<td>0.153</td>
<td>The effect on average speeds for day of the week is insignificant.</td>
</tr>
</tbody>
</table>
TABLE 3 Summary of the comprehension/opinion survey.

(a) Question #1: "In this situation, you first reaction would be to"

<table>
<thead>
<tr>
<th></th>
<th>Switch lanes</th>
<th>Slow down</th>
<th>Pay more attention</th>
<th>Continue as normal</th>
<th>Look for work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dancing Diamond</td>
<td>29%</td>
<td>46%</td>
<td>13%</td>
<td>7%</td>
<td>5%</td>
</tr>
<tr>
<td>Flashing Diamond</td>
<td>27%</td>
<td>55%</td>
<td>10%</td>
<td>1%</td>
<td>7%</td>
</tr>
<tr>
<td>Flashing Box</td>
<td>26%</td>
<td>47%</td>
<td>15%</td>
<td>9%</td>
<td>3%</td>
</tr>
</tbody>
</table>

(b) Question #2: "What does this sign mean to you?"

<table>
<thead>
<tr>
<th></th>
<th>Shoulder work ahead</th>
<th>Use caution ahead</th>
<th>Proceed normally</th>
<th>Lane closure</th>
<th>Do not know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dancing Diamond</td>
<td>17%</td>
<td>59%</td>
<td>1%</td>
<td>8%</td>
<td>15%</td>
</tr>
<tr>
<td>Flashing Diamond</td>
<td>9%</td>
<td>67%</td>
<td>0%</td>
<td>7%</td>
<td>17%</td>
</tr>
<tr>
<td>Flashing Box</td>
<td>12%</td>
<td>55%</td>
<td>2%</td>
<td>4%</td>
<td>27%</td>
</tr>
</tbody>
</table>

(c) Question #3: "In your opinion, which of these three signs would best prompt safe driving near highway work?"

<table>
<thead>
<tr>
<th></th>
<th>Percentage of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dancing Diamond</td>
<td>54%</td>
</tr>
<tr>
<td>Flashing Diamond</td>
<td>43%</td>
</tr>
<tr>
<td>Flashing Box</td>
<td>3%</td>
</tr>
</tbody>
</table>

(d) Question #4: "In your opinion, which of these three signs would most likely be ignored?"

<table>
<thead>
<tr>
<th></th>
<th>Percentage of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dancing Diamond</td>
<td>1%</td>
</tr>
<tr>
<td>Flashing Diamond</td>
<td>1%</td>
</tr>
<tr>
<td>Flashing Box</td>
<td>94%</td>
</tr>
<tr>
<td>None of them</td>
<td>4%</td>
</tr>
</tbody>
</table>

(e) Question #6: "How old are you?" - Age distribution for survey respondents

<table>
<thead>
<tr>
<th>Age group</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 to 19 years old</td>
<td>9.5%</td>
</tr>
<tr>
<td>20 to 29 years old</td>
<td>25.7%</td>
</tr>
<tr>
<td>30 to 39 years old</td>
<td>16.0%</td>
</tr>
<tr>
<td>40 to 49 years old</td>
<td>24.8%</td>
</tr>
<tr>
<td>50 to 59 years old</td>
<td>11.4%</td>
</tr>
<tr>
<td>60 to 69 years old</td>
<td>8.0%</td>
</tr>
<tr>
<td>70 years old and older</td>
<td>4.6%</td>
</tr>
<tr>
<td>CAUTION DISPLAYS</td>
<td>Flashing Sequence 1</td>
</tr>
<tr>
<td>-----------------------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>&quot;Flashing Box&quot; or &quot;Flashing Four-Corner&quot;</td>
<td>![Image]</td>
</tr>
<tr>
<td>&quot;Dancing Diamonds&quot; or &quot;Alternating Diamonds&quot;</td>
<td>![Image]</td>
</tr>
<tr>
<td>&quot;Flashing Diamonds&quot;</td>
<td>![Image]</td>
</tr>
<tr>
<td>&quot;Bar&quot; or &quot;Flashing Line&quot;</td>
<td>![Image]</td>
</tr>
<tr>
<td>&quot;Alternating Two-Corner&quot;</td>
<td>![Image]</td>
</tr>
</tbody>
</table>

FIGURE 1 Various forms of caution displays.
Up to 1.6 km (1 mile). Far enough away not to be influenced by the test site or ramps.

*Note: Move signs 5.2 m (17ft) away from roadway during non-test times.

FIGURE 2 Typical field experiment layout.
(a) Urban locations

(b) Rural locations

FIGURE 3 Field test locations.
THANK YOU!
HONESTLY MARK THE BEST ANSWER (ONLY ☐ ONE BOX).

1. In this situation, your first reaction would be to:
   - [ ] Switch lanes if possible
   - [ ] Slow down
   - [ ] Pay more attention
   - [ ] Continue normal driving
   - [ ] Look for highway work

2. What does this sign mean to you?
   - [ ] Shoulder work ahead
   - [ ] Use caution ahead
   - [ ] Proceed normally (Highway work has ceased for now)
   - [ ] Lane closure ahead
   - [ ] Do not know

3. In your opinion, which of these three signs would best prompt safe driving near highway work?
   - [ ] Flashing Box
   - [ ] Alternating Diamonds
   - [ ] Flashing Diamonds

4. In your opinion, which of these three signs would most likely be ignored?
   - [ ] Flashing Box
   - [ ] Alternating Diamonds
   - [ ] Flashing diamonds
   - [ ] None of them

5. Gender
   - [ ] Male
   - [ ] Female

6. How old are you?
   - [ ] 16 to 19
   - [ ] 20 to 29
   - [ ] 30 to 39
   - [ ] 40 to 49
   - [ ] 50 to 59
   - [ ] 60 to 69
   - [ ] 70 +

7. How much time do you spend driving during a typical workday?
   - _____ hours _____ minutes

8. Which U.S. state have you done the most driving in?
   - _______________ (State)

9. Which county have you done the most driving in?
   - _______________ (County)

10. Pick your candy bar and enjoy!

Note: AD = Alternating Diamonds, FD = Flashing Diamonds, FB = Flashing Box

FIGURE 4 Comprehension/opinion survey form.
FIGURE 5  Speed reduction plots.