



**Public Opinion and Understanding of
Advance Warning Arrow Displays Used in
Short-Term, Mobile, and Moving Work
Zones**

Technical Report 45110-1

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The University of Kansas
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16. Abstract In long-term work zones on multilane highways and/or freeways, the Federal Highway Administration has interpreted the Manual on Uniform Traffic Control Devices to mean that only one advance warning arrow displays can be used to denote the closure of a single lane. Where two or more lanes are closed, a single arrow display is used for each lane to be closed. However, in short duration, mobile, and moving work convoys the MUTCD allows the use of multiple arrow displays to indicate a single lane closure. These disparate uses for arrow displays create the potential for confusion by drivers. This paper describes the results of four focus group interviews with Midwestern drivers. Participants were shown several mocked images of shadow work vehicles with arrow displays and were questioned on how well they understood and/or interpreted the message conveyed by arrow displays depending on the display type and quantity of displays used, and looked specifically for potential driver confusion. Focus group participants generally considered panel displays that included motion (e.g., sequential arrows and sequential chevrons) as implying a more important situation and preferred their use over flashing versions. While participants were receptive to the use of multiple arrow displays on multiple shadow vehicles, a minority indicated that this conveyed a need to move over more than one lane. Participants also indicated that staggering sequential shadow vehicles from the shoulder into the closed lane provided useful information as to the number and location of the closed lanes.			
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**PUBLIC OPINION AND UNDERSTANDING OF ADVANCE WARNING
ARROW DISPLAYS USED IN SHORT-TERM, MOBILE, AND MOVING
WORK ZONES**

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DISCLAIMER

This research was performed in cooperation with the Smart Work Zone Deployment initiative, a Federal Highway Administration (FHWA) pooled fund study administered by the Iowa Department of Transportation. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Smart Work Zone Deployment Initiative, the Iowa Department of Transportation, or the FHWA. This report does not constitute a standard, specification, or regulation. The engineer in charge of the study was Dr. Steven D. Schrock, Kansas P.E. #18989.

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TABLE OF CONTENTS

	Page
LIST OF FIGURES	viii
LIST OF TABLES	ix
1. INTRODUCTION	1
WORK PLAN.....	4
2. LITERATURE REVIEW	7
CAUTION INDICATIONS ON FLASHING ARROW DISPLAYS	8
3. DOT TELEPHONE SURVEY	9
4. FOCUSE GROUPS	13
PARTICIPANT DEMOGRAPHICS	13
FOCUS GROUP STUDY DESIGN	15
KEY FINDINGS.....	17
Individual Arrow Displays when Mounted on a Single Work Vehicle	17
Participants' Understanding of Single Arrow Displays.....	17
Comparison of Sequential Chevron Display with Curve Warning Chevrons	18
Participants' Preference of Arrow Display Based on Perceived Effectiveness	19
Multiple Arrow Displays when Mounted on Several Work Vehicles	19
Participants' Understanding of Multiple Arrow Displays	19
Participants' Opinions on Mixing of Multiple Arrow Displays	21
Static Signing on Work Vehicles.....	21
Individual Caution Displays when Mounted on a Single Work Vehicle.....	22
5. FINDINGS.....	23
6. REFERENCES	25
APPENDIX A. RESULTS OF TELEPHONE SURVEY OF STATE DEPARTMENTS OF TRANSPORTATION.....	26

LIST OF FIGURES

	Page
FIGURE 1 Typical advance warning arrow display at a long-term work zone (flashing arrow displayed).....	1
FIGURE 2 Typical advance warning arrow display at a long-term work zone (chevron displayed).....	2
FIGURE 3 Typical application of mobile operation on multi-lane road.....	3
FIGURE 4 Typical advance warning arrows displayed on work convoy shadow vehicles (arrows displayed).....	4
FIGURE 5 Flashing arrow panel display guidance from the MUTCD.	5
FIGURE 6 State departments of transportation surveyed by telephone.....	9
FIGURE 7 Advance warning arrow and caution displays presented to focus groups.....	16
FIGURE 8 Focus group images showing single work vehicles equipped with arrow display.	18
FIGURE 9 Focus group images showing multiple work vehicles equipped with arrow displays.	20
FIGURE 10 Focus group images showing single work vehicles equipped with caution displays.	22

LIST OF TABLES

	Page
TABLE 1 Recommended Luminous Intensity Requirements	8
TABLE 2 State Departments of Transportation Use of Standards in Addition to the MUTCD	10
TABLE 3 State Departments of Transportation Use of Different Arrow Displays.....	10
TABLE 4 Targeted Focus Group Participant Demographics by Location.....	14
TABLE 5 Actual Focus Group Participant Demographics by Location	15
TABLE A1 Policies Governing Short-Term, Mobile, and Moving Work Zones by State	28
TABLE A2 Type of Panel Display used by State Department of Transportation.....	30

1. INTRODUCTION

In work zones where the traffic control plans are relatively static – such as at long-term work zones where construction work occupies the location for several days or longer (*1*) – the use of a single advance warning arrow display as shown in Figures 1 and 2 to indicate a single closure appears well standardized and well understood by the driving public. In fact, the Federal Highway Administration (FHWA) has interpreted the Manual on Uniform Traffic Control Devices (MUTCD) as meaning that only one arrow display is to be used for each lane closed in long-term situations (*2,3*).

However, in short duration work zones where activities take 15 minutes or less to complete and at mobile work zones where the activity location is continually changing (*1*), there is often a desire by highway departments and contractors to employ additional equipment or alternative uses of arrow panels to alert drivers they are approaching a work zone. Because these types of



FIGURE 1 Typical advance warning arrow display at a long-term work zone (flashing arrow displayed).



FIGURE 2 Typical advance warning arrow display at a long-term work zone (chevron displayed).

work zones often have fewer visual reinforcements to the lane closure message (e.g., minimal cones, barrels, or other channelizing devices), this desire seems understandable; workers desire better protection from errant vehicles and one common remedy is to add more signing based on the premise that ‘more is better.’

Often there is a desire to use multiple arrow displays to indicate that a single lane is closed. In short duration and mobile applications the MUTCD does allow the use of multiple arrow displays to indicate a single lane closure, as shown in Figures 3 and 4 (3). This results in a situation where the same traffic control device (e.g., an arrow display) is used in a slightly different manner depending on the nature of the work zone:

- In a long-term work zone two arrow displays mean two lanes are closed.
- In a short term, moving, or mobile work zone two arrow displays may mean only a single lane is closed.

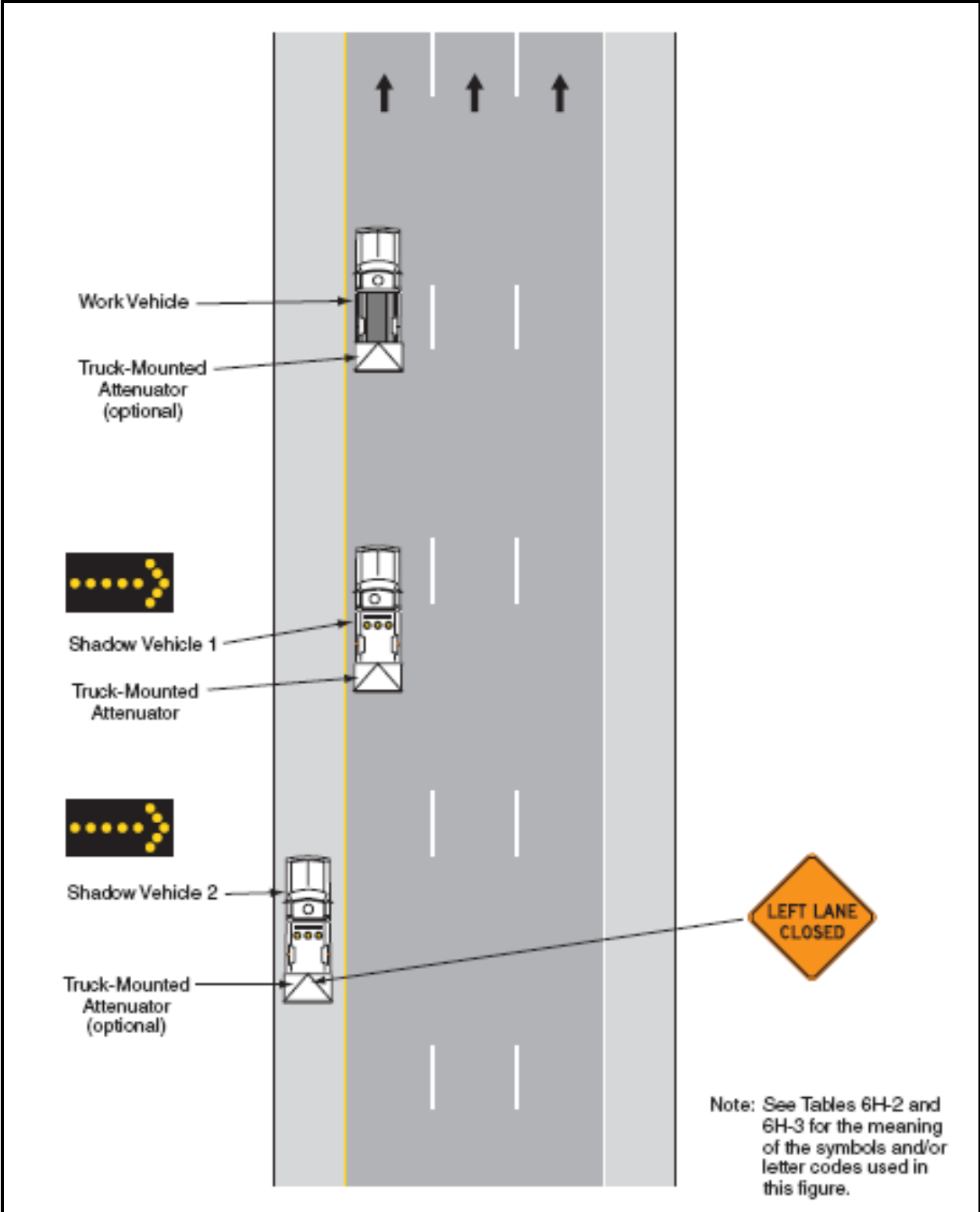


FIGURE 3 Typical application of mobile operation on multi-lane road (3).



FIGURE 4 Typical advance warning arrows displayed on work convoy shadow vehicles (arrows displayed).

These disparate uses for arrow displays create the potential for confusion by drivers, an issue that has not been reported on previously in the literature. This research was conducted to determine the extent that typical drivers are able to understand these uses of arrow displays, to explore any confusion resulting from these different uses, and to make suggestions on how to improve lane-changing information to drivers in short duration, mobile, and moving work zones.

Complicating matters, there are multiple forms that the actual arrows can take, as the MUTCD allows several allowable variations, as shown in Figure 5. These variations could confound any study of flashing arrow displays, and are taken into account in this research.

WORK PLAN

The research was conducted in two phases. Phase I (Tasks 1-3) involved an examination of the state of the literature and the state of the art regarding the use of arrow panel displays in short-

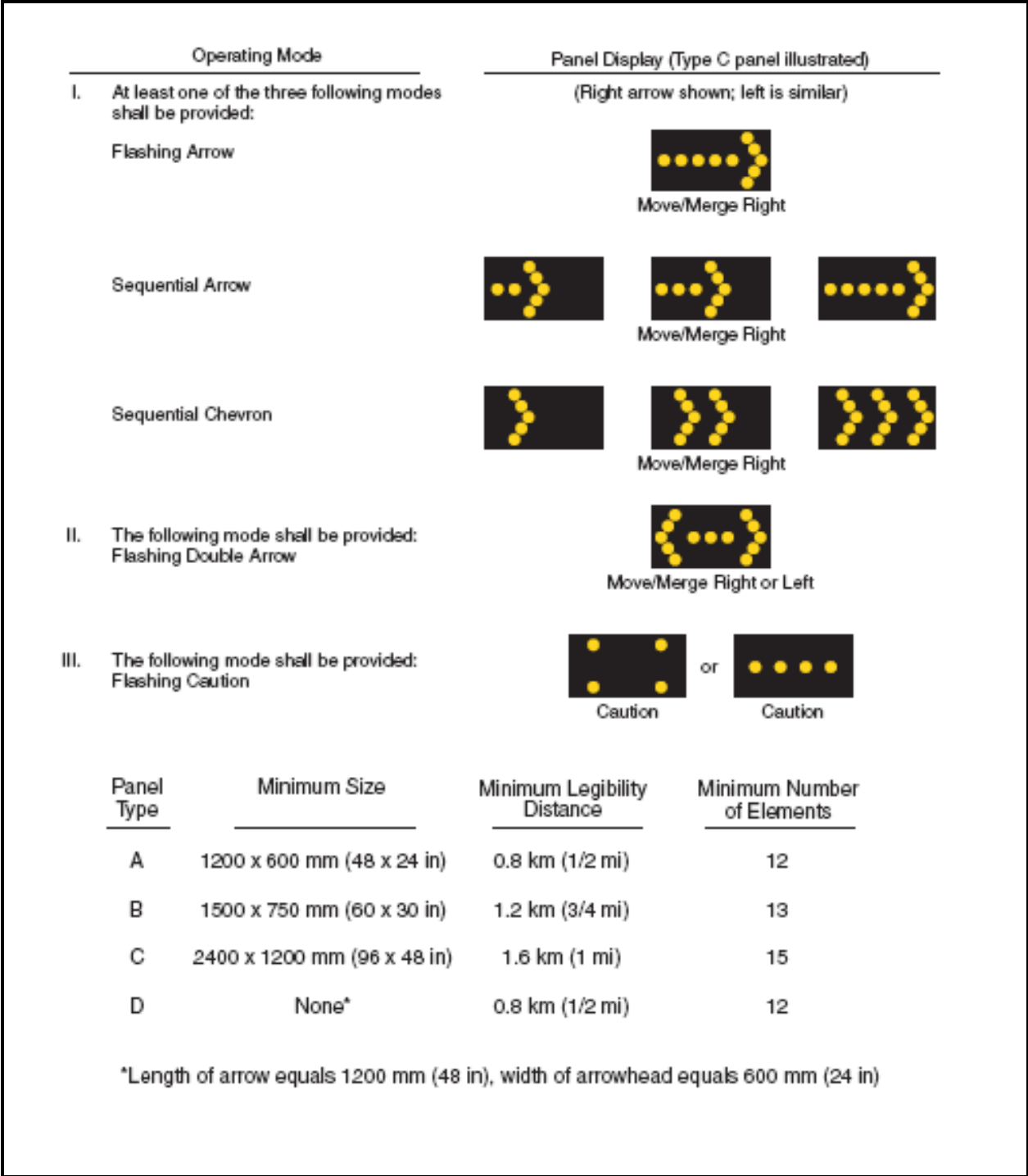


FIGURE 5 Flashing arrow panel display guidance from the MUTCD (3).

term, mobile, and moving work zones. Phase II (Task 4) involved a series of focus groups of drivers to better gauge their opinions and understanding of arrow panel displays. The work plan consisted of the following five tasks:

- Task 1: MUTCD Review
- Task 2: Literature Review
- Task 3: DOT Telephone Survey
- Task 4: Focus Groups
- Task 5: Report Preparation

The MUTCD application of arrow displays has been presented in this chapter. The remaining tasks are presented in the following chapters.

2. LITERATURE REVIEW

Early work with arrow displays consisted of the size and placement of the devices at long-term work zones. Graham, Migletz, and Glennon examined the effectiveness of the placement of arrow displays in the vicinity of work zone merge tapers (4). The researchers found that arrow boards were effective in moving traffic out of the closed lane compared to no arrow display. Additionally, the researchers found the displays were more effective when placed at the beginning of the merge taper. Conversely, the arrow displays were not as effective in changing driver behavior when used in other situations, such as at route diversions, traffic splits, or for shoulder closures. This seems to reinforce the idea that drivers associate the arrow display as a requirement to vacate a lane, but not necessarily a requirement to leave the roadway entirely.

Finley, Ullman, and Trout conducted driver surveys in 2004 to evaluate how well drivers understood the information presented on trucks in a moving work convoy in Texas (5). The signing on the convoy in question was varied throughout the study, and included:

- Static signing that explained the nature of the work as well as the number of vehicles in the convoy,
- Changeable message sign (CMS) displays showing the speed of the work convoy,
- CMS displays showing the speed of the approaching vehicle, and
- CMS displays showing both the speed of the work convoy and the speed of the approaching vehicle.

Subjects were shown picture images of the work convoy signing to determine their understanding of the information. In Texas, fully-paved shoulders are prevalent on all state roadways, and so it is common practice to direct motorists to use the shoulder to pass on the right of a slow-moving work convoy on two-lane roadways. Finley, Ullman, and Trout showed subjects four images showing information on the back of a work vehicle directing traffic to pass on the right: three different text-based CMS messages and - of interest for the current research project - a flashing arrow display directing traffic to move right. The flashing arrow display was understood by only 66 percent of the participants, whereas all of the different text messages were better understood (81, 83, and 97 percent, respectively). This seems to agree with the work of Graham, Migletz, and Glennon that flashing arrow displays are less effective when directing drivers to do something other than move into an adjacent travel lane.

Wooldridge, et al. researched test methods for how best to determine the brightness levels of arrow panels and CMSs (6). Specifically, they recognized that viewing an arrow panel at an angle can significantly reduce the effective output of its lights with respect to the viewers' location. By varying the luminous intensity levels during daytime operations at long-term work zones, the researchers examined how drivers reacted to the arrow panels. By observing the number of vehicles in the closed lane on the approach to the merge taper, the researchers found that there was a relationship between luminous intensity of the arrow panel and the lane-changing behavior of the drivers. This appears to be related to the distance from which drivers are able to see the arrow panel; during bright daytime conditions an arrow panel set to its lowest luminous intensity levels would be less likely to be seen from a distance. They recommended minimum luminous intensity values as shown in Table 1.

TABLE 1 Recommended Luminous Intensity Requirements (6)

Time of Day	Speed (mph)	Minimum On-Axis		Minimum Off-Axis		Maximum On-Axis
		cd ^a /lamp	cd	cd/lamp	cd	cd
Day	≥ 45	500	4000	100	800	NA
Night	≥ 45	150	1200	30	240	5500

a. cd = candela, the SI measure of luminous intensity

CAUTION INDICATIONS ON FLASHING ARROW DISPLAYS

While the MUTCD currently allows only two caution indications as shown in Figure 5 (e.g., four flashing lights in the display corners or four flashing lights in a horizontal line), there has been research to determine if other indications could perform as well or better as a general caution display. Turley, Saito, and Sherman evaluated a caution display strategy known as the “dancing diamonds” display which consisted of two diamond shapes moving horizontally back and forth on the display panel (7). This was a display used in Oregon from 1992 at least to the date of the research study in 2003. The researchers found during field studies that the dancing diamonds display was able to reduce mean speeds by 2 mph compared to the caution display consisting of one light displayed in each corner of the panel (as shown in Figure 3).

Additionally, the researchers found from a comprehension-opinion survey that drivers were more likely to state that the dancing diamonds display was the best method (of the displays shown) in promoting safe driving. This could be due to several factors, including driver bias; since this display had been used in Oregon for more than ten years at the time of the survey, drivers may have been acclimated to the display. Another factor could be that the display used more lights than the simpler caution display that used only four lights in the corners. It is possible that a more in-depth human factors study could have shown whether - all other things being equal - more lights or fewer lights would have an effect on driver opinions.

3. DOT TELEPHONE SURVEY

Telephone contact was made with 38 state departments of transportation to determine their use of flashing arrow displays in short-term, moving, and mobile work zones. The states contacted are shown in Figure 6. This represented 76 percent of all state DOTs nationally, and was considered to be a representative sample by the authors. The purpose of the telephone survey was to determine the following information:

- Whether each state followed the MUTCD or had an enhanced state manual with regards to short-term, moving, and mobile work zones;
- Lateral placement of shadow vehicles in short-term, moving, and mobile work zones;
- Any noteworthy variations or special practices used with regard to short-term, moving, and mobile work zones;

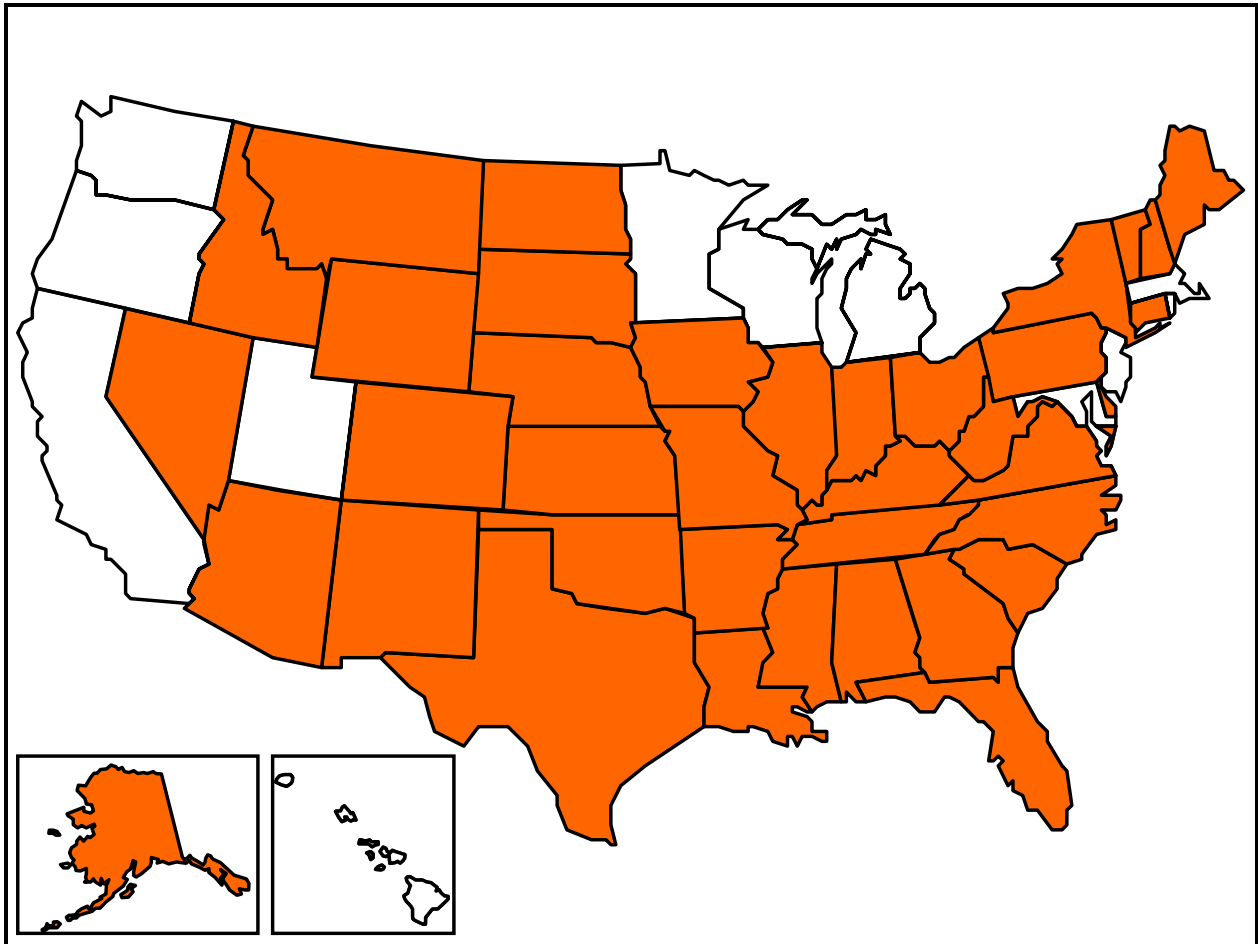


FIGURE 6 State departments of transportation surveyed by telephone.

A summary of the results of the survey are shown in Table 2, with each state’s individual data shown in Appendix A.

TABLE 2 State Departments of Transportation Use of Standards in Addition to the MUTCD

State Use of Standards in Addition to the MUTCD n = 38	Nature of Standards or Practices in Addition to the National MUTCD
No: 11 states (29 percent of states sampled)	N/A
Yes: 27 states (71 percent of states sampled)	<ul style="list-style-type: none"> • Require a minimum of three shadow vehicles. • Require police presence at the upstream end of the work convoy. • Require STAY BACK 500 FT sign for some types of work activities. • Require the use of light dimmers on flashing arrow displays when operating at night. • Require the work convoys speed to be at least 3 mph. • Require truck-mounted attenuators on shadow vehicles.

Additionally, the state DOTs were asked which of the arrow-type displays are typically used in their states: flashing arrows, sequential arrows, or sequential chevrons. State-by-state details are shown in Appendix A, and are summarized in Table 3. Note that because many states allowed two or even three of the different display types, the sum of the responses shown in Table 3 exceeds the number of participating states.

TABLE 3 State Departments of Transportation Use of Different Arrow Displays

Display Type	Number of States Using This Display Type n = 38
Flashing Arrow	28 (74 percent of states sampled)
Sequential Arrow	25 (66 percent of states sampled)
Sequential Chevron	19 (50 percent of states sampled)

Interestingly, there was little difference among the states in their use of the flashing arrow and the sequential arrow (74 percent and 66 percent, respectively). There appeared to be a lower rate in the use of the sequential chevron, with only 50 percent of states reporting its use.

Nineteen states (50 percent of those participating in the survey) reported limiting arrow displays to a single type of display in their state. The distribution of these single-display display states is interesting:

- Flashing arrow: 10 states (26 percent of the surveyed states)
- Sequential arrow: 7 states (18 percent of the surveyed states)
- Sequential chevron: 2 states (5 percent of the surveyed states)

Of the states that limited arrow displays to a single arrow type, there was a definite preference for arrow displays as opposed to a chevron display, and a slight preference for a flashing display as opposed to a sequential display.

There appears to be little agreement in the practices among the various states. While all are compliant with the MUTCD, many states have slight variations, and still others choose not to use some of the arrow display types. This leads to the possibility of confusion by drivers, which the researchers attempted to gain a better understanding of in the next chapter.

4. FOCUS GROUPS

Focus group meetings were conducted in order to gain a better understanding of the views and opinions of the driving public as to how well they understood the information conveyed from the various displays on an arrow panel, which methods were preferred, and what alternatives might be useful for the driving public. Focus groups have advantages over other survey methods in that they are able to cover a topic in more depth, and due to the open-ended nature of the discussions, the potential existed for innovative concepts to be suggested by participants (8). Areas of emphasis that were discussed during the focus groups included the following:

- What the various arrow displays mean to the driving public,
- How participants interpreted the difference between a single arrow display and multiple arrow displays,
- What the various caution displays mean to the driving public, and
- What driving actions participants believe they would take when confronted with various arrow panel displays.

Additionally, participants were asked what they would prefer to see changed with respect to advance work zone traffic control applications in short-term, mobile, and moving freeway operations.

Four focus groups were conducted in four cities in three Midwestern states in order to provide a diverse group of participants. Focus groups were conducted in Kansas City, Missouri; Lawrence, Kansas; Overland Park, Kansas; and West Des Moines, Iowa.

PARTICIPANT DEMOGRAPHICS

Focus group participants were recruited with the goal of having a diverse population of licensed drivers. Requirements for individual participants included: having a valid driver license, driving at least 8,000 miles per year, and driving on a freeway at least once per month. Additionally, it was desired to match as closely as possible the demographics of the overall driving population with respect to gender, age, and level of education. Table 4 shows the demographics percentages obtained from the U.S. Census Bureau and U.S. Department of Transportation FHWA for the population's education level and the age of licensed drivers in the three states where focus groups were held (9,10). For the demographics category of age, all of the percentages were calculated based on state licensed drivers instead of the total state population.

Table 5 shows the actual demographic percentages of the 34 participants that took part in the focus groups. The targeted demographic distribution and the overall distribution of actual participants compared reasonably well, although a better match was not achieved due to last-minute cancellations by several would-be participants. Additionally, finding some demographic groups was problematic, such as participants with less than a high school education and the oldest age group. Overall, the actual demographic results indicated that a good cross-section of the driving public was achieved; this was an encouraging indication that the comments provided could be considered representative for the areas where the focus groups were conducted.

TABLE 4 Targeted Focus Group Participant Demographics by Location

	Kansas City, Missouri	Lawrence, Kansas	Overland Park, Kansas	West Des Moines, Iowa	Average
Gender					
Male	49%	49%	49%	49%	49%
Female	51	51	51	51	51
Total	100	100	100	100	100
Age					
Under 25	15	16	16	15	16
25 – 39	26	26	26	24	25
40 – 64	44	42	42	44	43
Above 65	15	16	16	17	16
Total	100	100	100	100	100
Education Level					
No High School Degree	15	12	12	11	13
High School	34	30	30	36	32
Some College	29	32	32	31	31
College Degree	22	26	26	22	24
Total	100	100	100	100	100

Source: U.S. Census Bureau and the Federal Highway Administration.

TABLE 5 Actual Focus Group Participant Demographics by Location

	Kansas City, Missouri	Lawrence, Kansas	Overland Park, Kansas	West Des Moines, Iowa	Average
Gender					
Male	43%	43%	44%	45%	44%
Female	57	57	56	55	56
Total	100	100	100	100	100
Age					
Under 25	14	28	33	0	19
25 – 39	43	43	45	64	49
40 – 64	43	29	11	18	25
Above 65	0	0	11	18	7
Total	100	100	100	100	100
Education Level					
No High School Degree	0	0	0	18	2
High School	14	0	33	0	14
Some College	14	55	22	27	30
College Degree	72	45	45	55	54
Total	100	100	100	100	100

FOCUS GROUP STUDY DESIGN

Each focus group meeting consisted of five main parts. The first part served as an orientation where the research team explained the research goals of the project, how the focus group would be conducted, and an explanation of any questions that the participants had. The second, third, and fourth parts of the discussions consisted of explorations of participants’ opinions and understanding of the following:

- Individual arrow displays when mounted on a single work vehicle,
- Multiple arrow displays when mounted on several work vehicles, and
- Individual caution displays when mounted on a single work vehicle.

The final part of the focus group meeting consisted of an open-ended discussion about what participants thought could be a way to change the advance warning area traffic control layout for short-term, mobile, and moving work zones.

The arrow displays which were used in this research are shown in Figure 7. Each arrow display was presented within a conceptualized image of a rural freeway scene showing one or more work vehicles, representing the advance warning shadow vehicles for a short-term, mobile, or moving work convoy equipped with arrow displays. The images were intentionally conceptualized to keep from showing participants extraneous levels of detail that would have

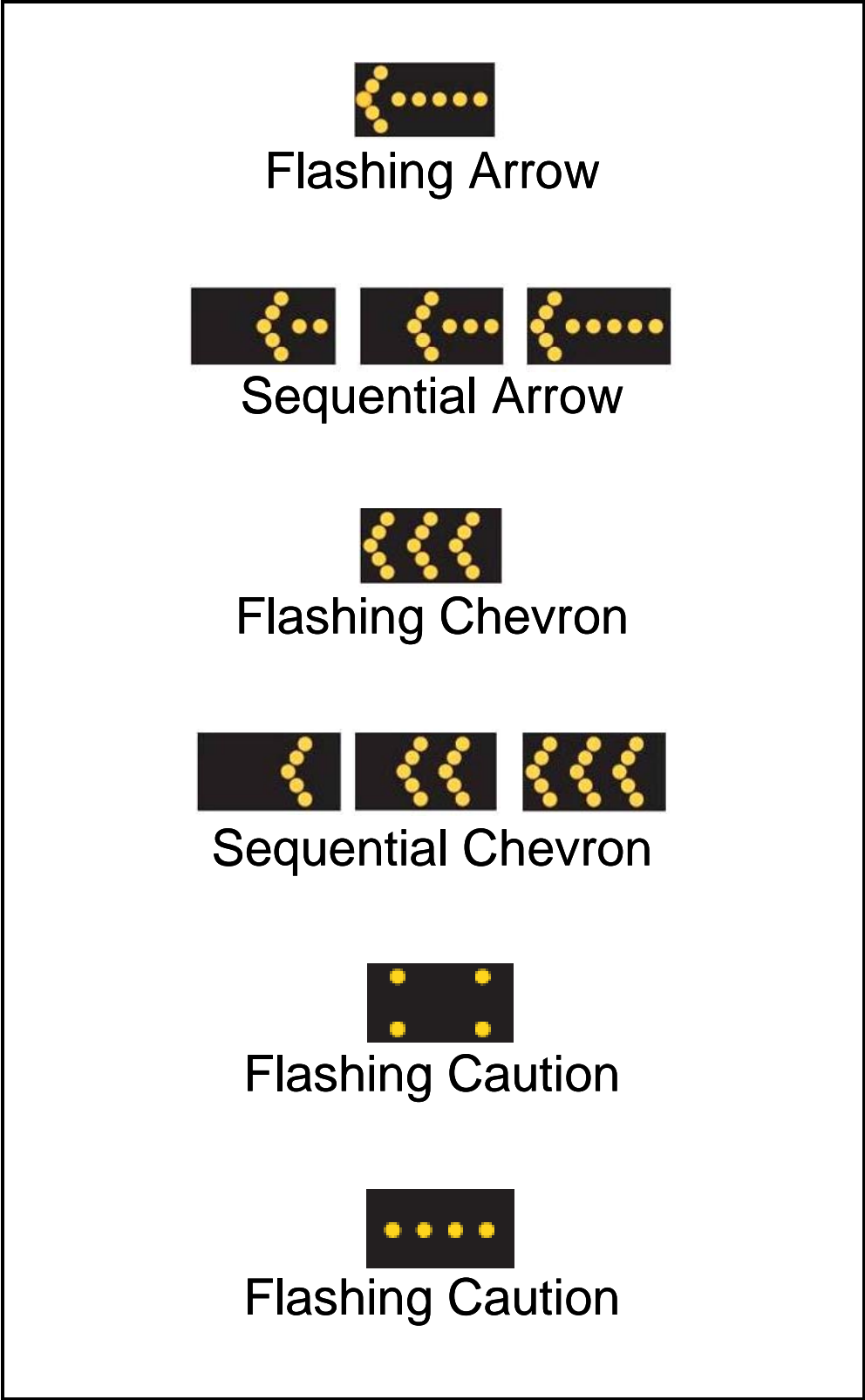


FIGURE 7 Advance warning arrow and caution displays presented to focus groups.

inevitably occurred if real photographs had been used. The images were intended to show the vehicles just upstream from the crest of a vertical curve, and this was explained at length to the participants; this meant that participants had to rely solely on the advance warning to know what lay ahead. Participants were told that they were approaching the work vehicle(s) from the right lane of a six-lane freeway. The images were displayed to the participants on a projection screen for several minutes while discussions about the specific arrow display(s) took place. The arrows and chevrons in the images flashed and moved sequentially as appropriate when presented to the participants.

KEY FINDINGS

Individual Arrow Displays when Mounted on a Single Work Vehicle

Figure 8(a) shows the first image shown to the participants - a representation of a shadow vehicle equipped with a flashing arrow display and moving slowly on the shoulder of a rural freeway. Participants were asked what they thought was happening, and what they were being told to do by the traffic control devices. The same questions were asked of participants when the same image was shown with a sequential arrow (Figure 8(b)), flashing chevron (Figure 8(c)), and sequential chevron arrow (Figure 8(d)) displayed instead. These cases were designed to examine whether the driving public would associate the specific image on the arrow display with a closed lane, and also the participants' preference. While the flashing chevron is not included in the MUTCD, it was included in this research to determine the extent that it was understood and preferred by focus group participants.

Participants' Understanding of Single Arrow Displays

Participants generally understood that they were being directed to move over when shown the image in Figure 8 (a).

- Twelve percent of participants indicated that a lane change was not required, but that drivers were only being asked to use caution.
- Seventy-six percent of participants indicated that they were being directed to move over one lane. However, of these participants, several indicated that they were unlikely to comply unless they were presented with additional information or were forced to do so through more active measures, such as moving a work vehicle into the closed lane.
- Twelve percent of participants indicated that they were being directed to move as far to the left as possible, in this case two lanes. A few participants also indicated that they would move all the way to the left lane not because of the arrow display, but because they were uncomfortable driving near a large work vehicle.

Interestingly, in all four focus group locations participants indicated that the sequential displays seemed to indicate a more important or critical situation due to the movement within the display.

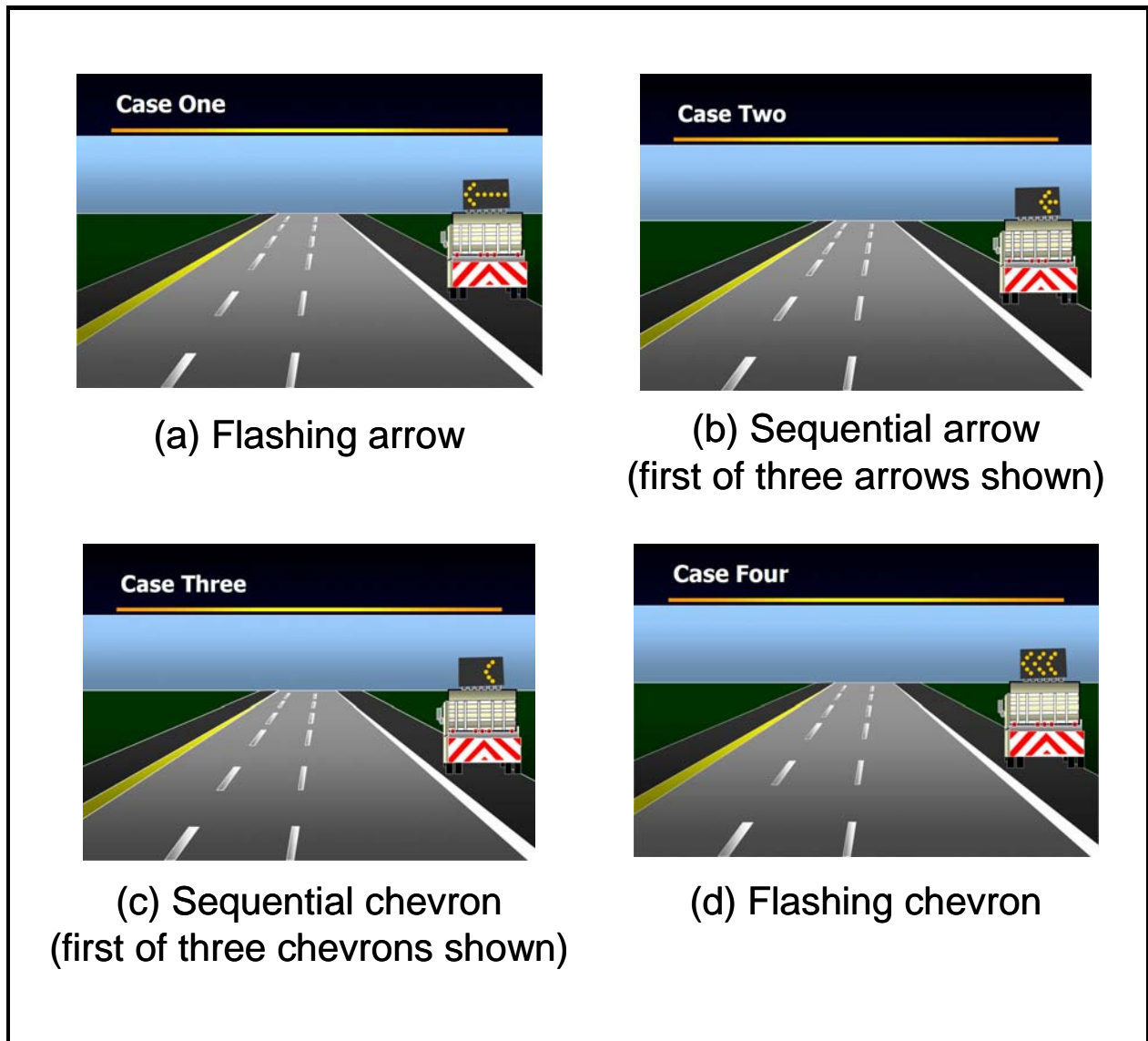


FIGURE 8 Focus group images showing single work vehicles equipped with arrow display.

Comparison of Sequential Chevron Display with Curve Warning Chevrons

In each of two focus group meetings a participant pointed out that the sequential chevron display (Figure 8(c)) seemed to be indicating that there was a sharp curve just over the hill rather than a lane closure. This potential discrepancy in meaning is a point of concern for the use of chevron displays compared to arrow displays. Participants did not have this reaction from the flashing chevron display or either of the arrow displays.

Participants' Preference of Arrow Display Based on Perceived Effectiveness

Participants were also asked to rate which arrow display they preferred to see based on which one they believed was most effective in conveying a lane closure message. The participant preferences included the following:

- Sequential Arrow (43 percent considered this display the most effective);
- Sequential Chevron (35 percent);
- Flashing Arrow (19 percent); and
- Flashing Chevron (3 percent).

As noted above, participants were more likely to rate sequential displays as more effective than their flashing counterparts. Only one participant considered the flashing chevron as the most effective. Some participants stated their dislike of this display, indicating that from a distance a flashing chevron display could be mistaken with a board full of lights rather than three arrowheads.

Multiple Arrow Displays when Mounted on Several Work Vehicles

Participants were shown several images of two or three work vehicles in various configurations. Each of these images is shown in Figure 9. These images were shown one-at-a-time to participants for several minutes, starting with the image shown in Figure 9(a) and ending with Figure 9(e).

Generally, participants agreed that they were approaching a larger and/or more extensive work zone operation when two work shadow vehicles could be seen instead of one. At each of the four focus group locations participants noted that in the images shown in Figure 8 they thought it possible that the entire work zone might consist of just the one truck that was visible, and could be a single worker collecting trash from the roadside, for example; the presence of two trucks meant that this was not the case. This finding could mean that when a convoy crosses the crest of a vertical curve there may be some advantage in leaving more than a single vehicle behind to alert traffic that they are approaching a work zone.

Participants' Understanding of Multiple Arrow Displays

When shown Figures 9(a) and 9(b) all of participants indicated that they would move over at least one lane.

- None indicated they would remain in the right-hand lane.
- Eighty-eight percent of participants indicated they were being directed to move over one lane. A few of these participants also commented that they thought this would be an ineffective way of closing two or more lanes.
- Twelve percent of participants misinterpreted this to indicate multiple lanes were closed. However, as with the images shown in Figure 8, a few of these participants also indicated that they preferred to move over as far as possible regardless of what signs were shown because they disliked driving next to large work vehicles.

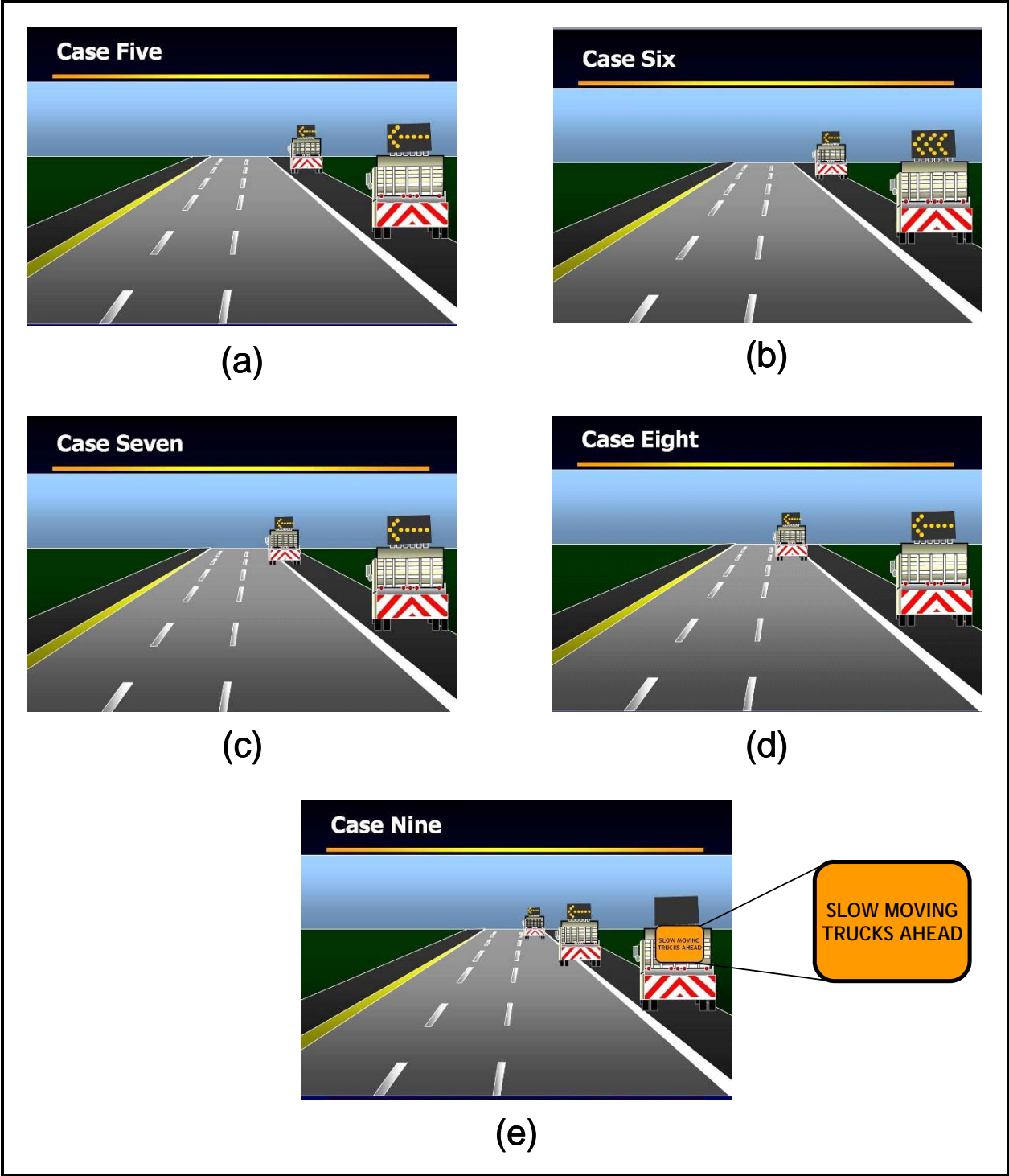


FIGURE 9 Focus group images showing multiple work vehicles equipped with arrow displays.

These participants remained consistent when shown all of the images in Figure 9 for all four focus groups. This indicates that most motorists are likely to correctly interpret that one lane is closed with multiple arrow displays in a moving convoy.

A few participants in each focus group admitted that, although they understood they were being directed to vacate the right lane in Figures 9(a), they would prefer to drive over the crest of the vertical curve and see for themselves that the lane is actually closed. As expected, this was not an issue for the images shown as Figure 9(c), (d) and (e). Indeed, participants generally approved of this staggered approach, indicating that this gave positive information regarding the lane closure, and would get compliance from even aggressive drivers who would have preferred to remain in the right-hand lane.

Participants' Opinions on Mixing of Multiple Arrow Displays

Figure 9(b) was presented in order to gauge participants' opinions on mixing several arrow display types within the same work zone. When shown this figure, participants were universal in their dislike of displaying different arrow types on two vehicles.

- Example comments by participants were that if they saw this on a real highway they might be inclined to wonder if these two vehicles were part of the same operation or if they were two unassociated individual vehicles that just happened to be in the same vicinity.
- Many participants also commented that at a minimum it appeared that the two truck operators were “not on the same page,” and that this reduced the credibility of the message they were conveying to drivers.

These are important statements, because in short-term, mobile, and moving work zones the limited traffic control provided by the shadow vehicles is often the only effective safety device protecting workers. If the credibility of this message is degraded it could correlate to an increased safety risk to workers. While presenting multiple arrow types in a single work area is not disallowed by the MUTCD, many individual states have policies stating that only one arrow type be used statewide, or that only one type be used for any given work zone.

Static Signing on Work Vehicles

One final issue discussed in this section of the focus groups was the sample text sign shown in Figure 9(e). Participants were generally in favor of having additional information about the work zone they were approaching. When asked what information would be appropriate to show on such a sign, participants were divided in their opinions at each of the focus group locations.

- One group of approximately half of the participants wanted to know what activity was taking place. These participants were interested in what was going on with the work: were they approaching a painting operation that might spray paint on their vehicle? Were they approaching a work area where workers would be out of vehicles and near the traveled lanes?
- Another group of approximately half of the participants wanted to know what they were supposed to do. These participants were less interested in what was happening, and

stated a preference for positive directions, such as MOVE OVER, RIGHT LANE CLOSED, or MOVE LEFT.

Individual Caution Displays when Mounted on a Single Work Vehicle

Participants were shown two images of single work vehicles with caution displays. These images are shown in Figure 10. These images were shown one-at-a-time to participants for several minutes. Participants were unsure when asked what information the displays were conveying to drivers and indeed initial reactions by several participants was that the first display shown (Figure 10(a)) did not mean anything. Upon further consideration the participants began to believe that the message indicated that they should approach the situation with caution, just as if the vehicle were sitting on the shoulder with hazard lights or flashing amber light. While this is the correct answer, the participants admitted to being less confident in their answers than in earlier sections of the focus group. When told that these were caution displays, comments given by participants included:

- If the work vehicle has a flashing amber light, is the caution display even necessary?
- There was the possibility that the flashing caution display shown in Figure 10(b) could be confused with an arrow display with several light bulbs burned out.

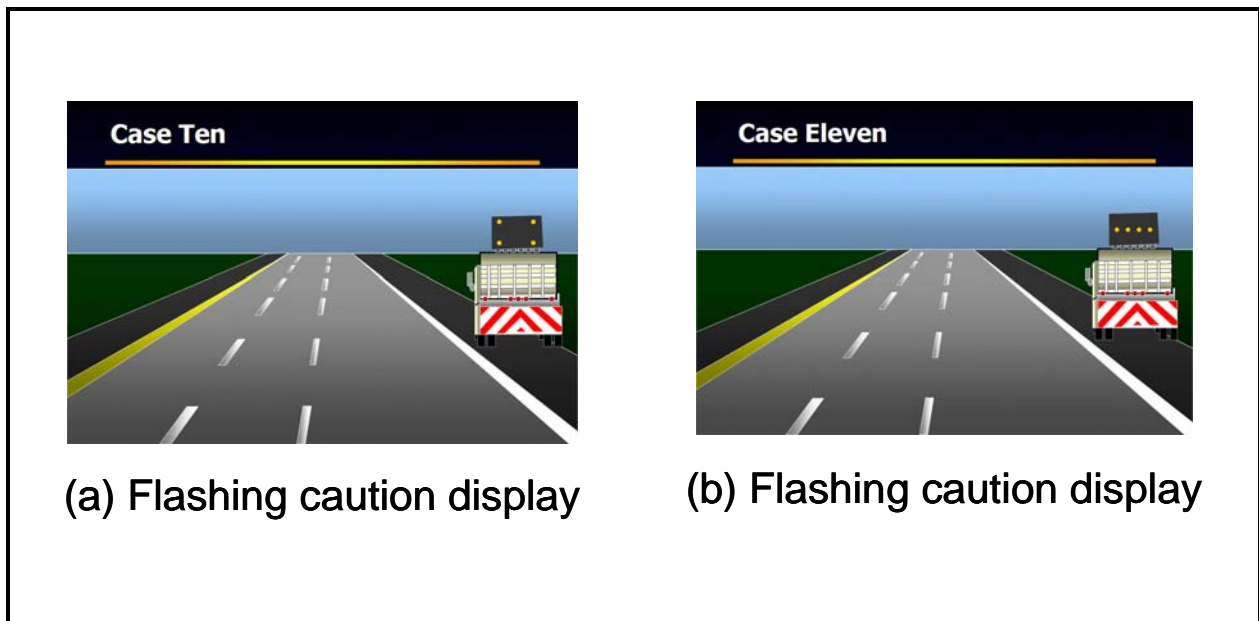


FIGURE 10 Focus group images showing single work vehicles equipped with caution displays.

5. FINDINGS

Several interesting findings were uncovered through the focus group meetings. These include the following:

- A few subjects indicated that the sequential chevron display looked more like a “curve ahead” warning than a lane closure warning.
- Seventy-eight percent of participants indicated that they preferred sequential displays over flashing displays. Reasons given were that the sequential movement of these displays indicated a more important or critical situation compared to the flashing alternatives.
- Almost none of the participants thought the flashing chevron was the most effective arrow display. Given that this display is not currently included in the MUTCD, there seems to be no justification for including it in future versions of the Manual.
- Eighty-eight percent of participants understood that multiple arrow displays in a work convoy indicate a single lane closure. Twelve percent of participants misunderstood the message to mean multiple lane closures.
- Participants were generally favorable of staggering work vehicles into the closed lane (as shown in Figures 9(c) through (e)), indicating that this provided positive reinforcement of the lane closure message.
- Participants were universal in their disapproval of mixing arrow displays within the same work convoy. There is no language in the MUTCD discouraging or prohibiting the mixing of multiple arrow displays in a single work zone. However, comments from the focus groups indicate that drivers may view such displays as having reduced credibility, indicating that national-level consideration of such language may be needed.
- Participants liked the idea of including additional information in the form of static signing on the back of the shadow vehicles, but there was no agreement on the nature of the information. Some participants wanted to know more about the nature of the work being performed, while others were only interested in information on what they were being directed to do. Further research is needed to determine what would be a more effective static message(s) displayed on the rear of shadow vehicles.
- Caution displays were ultimately understood by participants, but participants were less confident in their responses than for other focus group questions, and there was some discussion about whether such displays were even needed if other devices such as flashing amber lights were present.

In conclusion, while a high percentage of participants understood most of the lane closure messages that were displayed, there are several areas of improvement that need to be pursued in order to make traffic control more clear and effective at short-duration, mobile, and moving work zones. Each of the findings presented indicate avenues for field research into improving the use and understanding of arrow displays.

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APPENDIX A. RESULTS OF TELEPHONE SURVEY OF STATE DEPARTMENTS OF TRANSPORTATION

For the telephone surveys, contact was made with state DOTs to determine the manner that arrow panels are used in short term, short duration, and mobile work zones in each state, and the written policies or standard traffic control plan sheets that are in place guiding the use of arrow panels. These telephone surveys also enquired about any innovative operations that have been tried and the perceived results of these innovations.

Table A1 shows the typical location of moving convoys used in short term, short duration work zones by state DOTs. An 'M' marked in the standard/policy column indicate the state DOTs do not have a state-specific policy or standard relating to the number of vehicles in a moving or mobile operation that have and use arrow panels but refer to the MUTCD for guidance. A checkmark in the standard/policy column of the tables indicate that there is a policy or standard (in addition to the MUTCD) relating to a moving or mobile operation that have and use arrow panels. Any specific comments given regarding how the state policy or standard differs from the MUTCD is provided in the notes section. In some cases the interviewees believed that there were state policies, but were unable to determine how these differed from the MUTCD. In these events, it may be possible that the state policies were simply reflections of the MUTCD, but this was not determined at the time of the telephone survey.

A total of 38 state DOTs participated in the survey. More than half of the state DOTs responded that there are written policies or standard traffic control plan sheets in place to guide the use of arrow displays. Material from telephone surveys showed that the Louisiana Department of Transportation and Development requires the presence of a police vehicle in between the moving convoys, whereas the West Virginia DOT requires the presence of a police car behind the moving convoys to ensure drivers approach the work zone with caution. The interviewee from the Wyoming DOT responded during the telephone survey that they require the presence of additional shadow vehicles in the short term work zones.

Table A2 lists the typical types of panel display used in short term work zones by state DOTs. A checkmark in each of the type of panel display columns; flashing arrow, sequential arrow, and sequential chevron indicate that DOT allows the use of that display panel type. The rules and regulations are found in the note column.

Based on Table A2, it was found that not all DOTs use only the Type C panels; Type A through D are commonly used as well. The state DOTs of Illinois, New York and Texas are the three states that do allow arrow panel types other than Type C. The plans provided by the New York State DOT showed that the DOT permits the use of W1-11D or W1-12D warning signs next to the moving convoys instead of using arrow panels. In the case of Oklahoma, the DOT has adopted the policy to use Type B arrow panels only, whereas the Kentucky Transportation Cabinet allows the use of Type B arrow panels or larger. It was also found in this telephone survey that the Pennsylvania DOT uses only Type D arrow panels. Specifications of the Pennsylvania DOT stated that Type D arrow panels must only be used for short term, short duration and mobile operation.

TABLE A1 Policies Governing Short-Term, Mobile, and Moving Work Zones by State

State	Standard/Policy M = MUTCD Only √ = State Enhancement	Note
Alabama	M	No additional standards
Alaska	M	No additional standards
Arizona	√	No additional standards (striping). Use auto dimmers but very few at night
Arkansas	M	No additional standards
Colorado	√	
Connecticut	√	
Delaware	√	
Florida	√	
Georgia	√	
Idaho	√	
Illinois	√	
Indiana	√	Require attenuator
Iowa	√	
Kansas	√	
Kentucky	√	
Louisiana	√	Require police vehicle in between
Maine	M	No additional standards
Mississippi	√	Striping, spraying, sweeping & clearing policy. Two lane facility & four dots flashing in corner
Missouri	√	Striping policy (stay back 500ft signs included)
Montana	M	No additional standards
Nebraska	√	
Nevada	M	No additional standards
New Hampshire	M	No additional standards
New Mexico	M	No additional standards
New York	√	
North Carolina	√	Moving caravan speed must be more than 3mph
North Dakota	√	
Ohio	M	No additional standards
Oklahoma	M	No additional standards
Pennsylvania	√	
South Carolina	√	

Table A1 (Cont.). Policies Governing Short-Term, Mobile, and Moving Work Zones by State

State	Standard/Policy M = MUTCD Only √ = State Enhancement	Note
South Dakota	√	Standard/Policy is old and is currently being rewritten
Tennessee	M	No additional standards
Texas	√	
Vermont	√	For interstate only
Virginia	√	
West Virginia	√	Police used at end of shadow vehicles lineup
Wyoming	√	Require additional shadow vehicle

TABLE A2 Type of Panel Display used by State Department of Transportation

State	Type of Panel Display Used			Note
	Flashing Arrow	Sequential Chevron	Sequential Arrow	
Alabama	√	√	√	
Alaska	√	√	√	
Arizona	√	√	√	
Arkansas			√	
Colorado	√	√	√	
Connecticut		√		Department approved arrow board only
Delaware	√			
Florida	√			
Georgia		√		
Idaho		√	√	
Illinois	√	√	√	Type A, B or C display panels only
Indiana	√	√	√	
Iowa		√		
Kansas	√	√	√	
Kentucky	√			Type B display panel or larger
Louisiana	√	√	√	
Maine			√	
Mississippi	√	√	√	Striping, spraying, sweeping & clearing policy
Missouri	√	√	√	Striping policy (stay back 500ft)
Montana	√	√	√	
Nebraska	√			
Nevada		√		
New Hampshire	√			
New Mexico	√	√	√	
New York	√			Can be substituted with warning sign W1-11D or W1-12D next to the moving convoy (Type A, B or C display)
North Carolina	√			Moving caravan speed must be more than 3mph
North Dakota	√	√	√	
Ohio	√		√	
Oklahoma	√	√	√	Type B display only
Pennsylvania		√		Type D display only
South Carolina	√	√		Sequential chevron not acceptable
South Dakota		√		Standard/Policy is old and is currently being rewritten
Tennessee	√	√	√	

Table A2 (Cont.). Type of Panel Display used by State Department of Transportation

State	Type of Panel Display Used			Note
	Flashing Arrow	Sequential Chevron	Sequential Arrow	
Texas	√	√		Flashing arrow: Type B or C display only Sequential arrow: Daytime only
Vermont	√			For interstate use only
Virginia	√			
West Virginia	√			Police used at end of shadow vehicles lineup
Wyoming		√		Require additional shadow vehicle