Traffic Control Devices Pooled Fund Study

Design and Evaluation of Selected Symbol Signs
Phase II

Final Report

November 2010

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The objective of the Traffic Control Devices Pooled Fund Study (TCD PFS) is to assemble a group composed of State and local agencies, appropriate organizations and the FHWA to 1) establish a systematic procedure to select, test and evaluate approaches to novel TCD concepts as well as incorporation of results into the MUTCD; 2) select novel TCD approaches to test and evaluate; 3) determine methods of evaluation for novel TCD approaches; 4) initiate and monitor projects intended to address evaluation of the novel TCDs; 5) disseminate results; and 6) assist MUTCD incorporation and implementation of results.

To join the TCD PFS, or for more information about the TCD PFS

- Contact Amanda Emo at (202) 493-3395 or contact Scott Wainwright at (202) 366-0857
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EXECUTIVE SUMMARY

The Traffic Control Devices Pooled Fund Study (TCD PFS) focuses on a systematic evaluation of novel TCDs, employing a consistent process that addresses human factors and operations issues for each TCD idea. As part of the PFS effort, the FHWA Human Factors Team evaluated proposed new traffic signs in order to ensure that the signs were effective when taking driver comprehension and legibility requirements into consideration. The seventeen (17) signs evaluated were:

- Combination Horizontal Alignment / Advisory Speed
- Congestion Ahead
- Do Not Enter
- Do Not Pass
- Electric Vehicle Charging Station
- Fallen Rocks
- Flagger Ahead
- Maximum Width
- No Left Turn Ahead
- Railroad Crossing on Leg of Roundabout
- Cross Street Preferential Lane Warning Signs
- Road Narrows
- Low Shoulder Warning Signs
- Survey Crew
- Trolley Crossing
- Uneven Lanes
- Winery

The goals of this study were to develop alternative sign designs and then test the designs for driver comprehension and legibility distances. Multiple alternatives for each sign were developed based on input from drivers about the critical factors of each sign.

The team then conducted 96 surveys to determine driver comprehension for each sign alternative. The surveys were administered to the general driving public. The survey was designed to gauge if participants understood a sign's intended meaning. The alternatives were then evaluated in the Highway Sign Simulator Laboratory to determine at what distance they become legible.

Based on driver input and the results of the comprehension and legibility testing, the research team provided recommendations on symbols that should be included in the next edition of the Manual on Uniform Traffic Control Devices (MUTCD). For some signs, the team was able to clearly recommend a new alternative (see Table 37 for a summary).

ACKNOWLEDGEMENTS

The authors of this report would like to thank the Traffic Control Devices Pooled Fund Study panel for their technical and financial support of the project. Federal Highway Administration's Human Factors Team employees of both FHWA and Science Applications International Corporation (SAIC) all participated in some role on this project. Gene Hawkins (Consultant) provided technical advice throughout the project. Additionally, Mary Anne Bertola (SAIC) and Douglas Cobb (SAIC) aided with the state-of-practice survey, data collection, and data reduction on this project. The authors would also like to thank Chris Monk (FHWA) and William Perez (SAIC) for their management support of this project.

DISCLAIMER

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 Federal Highway Administration (FHWA). The United States Government does not endorse products or manufacturers. Trade or manufacturers' names may appear herein solely because they are considered essential to the object of this report. This report does not constitute a standard, specification, or regulation.

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INTRODUCTION

Traffic signs provide an important communication tool that is used to convey regulatory, warning, and guidance information to road users. The process of understanding user requirements for a new sign is particularly important for symbol signs, which rely on a common non-verbal interpretation by a large and diverse population of drivers. In the study described in this report, researchers determined driver understanding and legibility for a series of potential signs.

BACKGROUND

The *Manual on Uniform Traffic Control Devices* (MUTCD) is the national standard for traffic control devices.[1] It contains the basic principles that govern the selection, design, installation, operation, and maintenance of traffic control devices. According to the MUTCD, traffic control devices "*notify road users of regulations and provide warning and guidance needed for the uniform and efficient operation of all elements of the traffic stream in a manner intended to minimize the occurrences of crashes*."[1] The MUTCD also states that for a traffic control device to be effective it should:

1. Fulfill a need;
2. Command attention;
3. Convey a clear, simple meaning;
4. Command respect from road users; and
5. Give adequate time for proper response.

A device cannot command attention if it is not conspicuous. Additionally, a device cannot convey a clear and simple meaning if the device is not comprehended. If a device is not understood, then the sign will not command respect from road users. If any of the three major driver-related properties are inadequate, then the traffic control device will not provide an adequate time for a proper response. Providing adequate time for a proper response is the most critical, because without proper response time, drivers will not be able to perceive problems and react to them in an adequate amount of time to maneuver their vehicles, which may ultimately lead to crashes.

The MUTCD also gives guidance for the design of traffic control devices. The MUTCD states in Section 1A.03:[1]

> "*Devices should be designed so that features such as size, shape, color, composition, lighting or retroreflection, and contrast are combined to draw attention to the devices; that size, shape, color, and simplicity of message combine to produce a clear meaning; that legibility and size combine with placement to permit adequate time for response; and that uniformity, size, legibility, and reasonableness of the message combine to command respect.*"

Regarding symbols signs, the MUTCD states the following in Section 2A.12:[1]

> "*Symbol designs shall in all cases be unmistakably similar to those shown in this Manual and in the "Standard Highway Signs and Markings" book… New symbol designs are adopted by the Federal Highway Administration based on research evaluations to determine road user comprehension, sign conspicuity, and sign legibility.*"

From this language, it is apparent that new sign symbols can be introduced only after being evaluated through research and formal adoption in the MUTCD by the Federal Highway Administration (FHWA). Although it is not difficult to design a sign that "seems" to be effective, it is important for transportation engineers to recognize that the driver might perceive the sign to mean something completely different, and may not act in the manner that is intended by the engineer. Therefore, it is essential to research the driver-related issues that exist when new traffic signs are introduced to the roadway environment, which is the focus of the effort documented in this report.

The Traffic Control Devices Pooled Fund Study (TCD PFS) focuses on systematic evaluation of novel TCDs and employs a consistent process that addresses human factors and operations issues for each TCD idea. By pooling resources and expertise rather than to perform several independent research studies across the country, the PFS provides local and state agencies faster response to their needs and faster response to new technologies with the right assessment skills and tools to enable consistent TCD idea identification and evaluation. The PFS efforts address TCD issues identified by local and state jurisdictions, industry, and organizations and aid in the compliance to the MUTCD rule-making process and incorporation of novel TCDs into the MUTCD.

The TCD PFS members chose to conduct Phase II of a study to evaluate the effectiveness of various concepts for new signs. The current document describes this study effort.

RESEARCH GOALS

As part of the PFS effort, the FHWA Human Factors Team conducted Phase II of a study to develop and evaluate proposed alternatives for new traffic signs. The goals of this study were to:

- Identify candidate text and symbol signs based on current practice through a literature review.
- Evaluate driver comprehension of candidate signs.
- Measure the legibility distance of selected candidate signs.
- Provide recommendations on signs that merit consideration for addition to the MUTCD.

The Pooled Fund Study Panel selected the following sign messages for symbol development and evaluation.

- Combination Horizontal Alignment / Advisory Speed
- Congestion Ahead
- Do Not Enter
- Do Not Pass
- Electric Vehicle Charging Station
- Fallen Rocks
- Flagger Ahead
- Maximum Width
- No Left Turn Ahead
- Railroad Crossing on Leg of Roundabout
- Cross Street Preferential Lane Warning Signs
- Road Narrows
- Low Shoulder Warning Signs
- Survey Crew
- Trolley Crossing
- Uneven Lanes
- Winery

RESEARCH APPROACH

The research approach consisted of four major elements: gathering information to develop alternatives, evaluating understanding of the alternatives, evaluating legibility of the best understood alternatives, and developing recommendations on use. The specific activities were the following:

- Conducted a state-of-practice survey to see what various state and international agencies are using to convey the target messages.
- Performed a laboratory study to evaluate comprehension of the meaning of the symbol alternatives.
- Determined the recognition distance of the better understood symbol signs.
- Drafted recommendations regarding the implementation of the signs that were evaluated.

LITERATURE REVIEW

There are many different research studies on the effectiveness of traffic signs, including evaluations of comprehension, legibility, and driver response. However, we were unable to identify a standard or generally accepted methodology for the evaluation of symbol signs.

Dewar and Ells identified a need for assessing methods for evaluating signs and other TCDs because there is little to suggest which currently employed methods provide the best information.[2] They indentified several factors that should be evaluated: meaning, attention value, legibility, processing time, learnability, and influence on driver behavior. In a later paper on symbol signing, Dewar described six criteria as being important in the evaluation and design of symbol signs including legibility distance, understandability, conspicuity, learnability, glance legibility, and reaction time.[3]

EVALUATIONS OF UNDERSTANDABILITY

Understandability, hereafter referred to as *comprehension*, has been measured a number of different ways by different researchers. Alicandri and Wochinger asked research participants to write their interpretation of the sign meanings and indicate what action they would take if the signs were seen on the roadway.[4] Katz et al. used a similar procedure except that multiple-choice questions were asked following participants' initial interpretation of sign meanings.[5] The multiple-choice test was used to examine whether participants made problematic inferences about different signs (e.g., whether an animal presence sign with a flashing beacon turned off meant that no deer were present). In both cases, images of the signs were used without a background or roadway scene. Picha et al. showed participants a picture of the sign in-context where the roadway background was included in the picture.[6] Next to this picture, a close-up view of the device was provided along with multiple-choice questions about each sign.

EVALUATIONS OF THE INFLUENCE ON DRIVER BEHAVIOR

Dewar and Ells indicated that "before-and-after" studies are one of the most frequently used methods for evaluating signs; however, they also pointed out that there are several problems with this method.[2] They suggest that three possible methods of evaluating signs include a field study under normal driving conditions, a modified field study using scaled down signs, and a laboratory experiment to determine reaction time. Reaction time was taken to be the amount of time between the onset of the stimulus and the activation of a voice-operated instrument that was triggered when the correct meaning of the sign was spoken. The three techniques were compared and it was determined that the overall trends and relationships were similar; however, the actual distances obtained in the simulator were less than those observed in the field. The concept of "optimal index" is also described by Dewar and Ells and is stated as "*the degree to which [a sign] conveys the intended message to a driver operating a vehicle in an actual driving situation*."[1]

LABORATORY EVALUATIONS

Desrosiers performed field and laboratory investigations to determine the effectiveness of traffic signs.[7] The author stated that laboratory studies eliminate problems dealing with environmental variables (weather, light, and traffic conditions) as well as reduce the time required to gather data and provide researchers with additional control over the experiment. Stimuli were presented using 16 mm color motion pictures. It was concluded that laboratory tests can replace field tests but to obtain the same legibility distances observed in the field, a correction factor must applied to distances obtained in the laboratory.

Zwahlen et al. suggested several that factors that contribute to the underestimate of legibility distances by laboratory studies. These include insufficient display resolution, insufficient luminance and contrast representation, no change in depth, small image vibrations, and non-uniform and less sharp symbol or legend contours.[8]

Sign research for both comprehension as well as recognition distances have been performed at Turner Fairbank Highway Research Center (TFHRC) in the past as shown in Philips et al.[9] Alicandri and Wochinger[4], and Mahach et al.[10] The Philips et al. study dealt solely with the use of the SignSim laboratory for determining comprehension and recognition distances. It was determined that relative recognition distances could be found in the simulator but actual recognition distances could not be obtained without further validation. It was determined that signs could be compared against each other for relative recognition; however the actual recognition distances could not be calculated.

The Mahach et al. study hoped to test the significance of the differences in recognition distance between the SignSim and the natural environment by using actual scaled signs in TFHRC's Photometric and Visibility Laboratory (PVL).[10] The study pointed out that the effect of the light on signs in a natural environment is different from the SignSim because in the SignSim, the light is diffused as a sign approaches. The result turned out to be that there was a significant difference between the recognition distances obtained in the SignSim from the PVL for almost all signs.

SUMMARY

For comprehension testing, previous researchers looked at both open ended as well as multiple choice responses to obtain information about various sign alternatives. This study will incorporate similar methods so that first, it can be determined if participants understand the general meaning of the signs and second, to determine whether or not participants understand certain specific characteristics of the signs.

The research indicates that TFHRC's Sign Simulator laboratory will provide acceptable data for relative recognition distances; however, scale factors may be required to provide actual recognition distances. A field study would be required to effectively relate the Sign Simulator results to field results. For comparing alternatives, the Sign Simulator is expected to provide the information required.

STUDY APPROACH

The initial step of this study was to perform a state-of-practice survey of selected concepts to see what various states and countries used for various sign alternatives. The details and results of this research are outlined in the following section.

DOMESTIC AND INTERNATIONAL STATE-OF-PRACTICE SURVEY

Examples of various domestic and international symbol signs were gathered and studied prior to the development of new symbol sign designs for this study. Images of signs were collected both internationally and domestically, from around the United States as well as several other parts of the world. The following consists of a description and background on each sign that was studied. Some of these signs have a version that already exists in the MUTCD or have at least been proposed to be added into the MUTCD.

- Combination Horizontal Alignment/Advisory Speed – The intended purpose of these signs (W1-1a and W1-2a in the 2003 and 2009 MUTCDs) is to confirm the beginning of a horizontal alignment change, or curve, in the roadway as previously indicated by the standard Horizontal Alignment (W1-1 or W1-2) sign at the advance placement distance, and remind road users of the advisory speed for the curve. These signs differ from the standard horizontal alignment warning signs because the advisory speed is included on the sign, rather than on a plaque below the sign. There has not been any research to determine whether the numerals on the sign (without "MPH") are understood to be the advisory speed.

- Congestion Ahead – A Congestion Ahead sign is used to warn of stopped traffic caused by a traffic control signal or in advance of a section of roadway that regularly experiences traffic congestion. A "BE PREPARED TO STOP" word message sign (W3-4) is included in both the 2003 and 2009 MUTCD for this purpose. The MUTCD states that the sign may be placed downstream from a Signal Ahead sign to warn of stopped traffic caused by a traffic control signal or regularly-occurring traffic congestion on a section of roadway. It may be supplemented with a warning beacon with a When Flashing plaque. There have not been any proposed symbol signs for this message in either the 2003 or 2009 MUTCD. In his Sign Synthesis[11], W. Scott Wainwright recommends the evaluation of the European/International symbol for congestion for future addition to the MUTCD.

- Do Not Enter - The Do Not Enter sign is to be used where traffic is prohibited from entering a roadway. The symbolic sign for this message first entered the MUTCD in 1971, replacing the former word message only sign. The symbol sign does also include the words within the sign. The description is the same in both the 2003 and 2009 MUTCD. In addition to the description, the MUTCD includes guidance and options that describe where the sign should be placed in respect to the driver and road. The 2009 MUTCD added a support sentence that section 2B.48 has information on an optional lower mounting height of the sign for certain circumstances. The sign was not discussed in the Sign Synthesis. The issue to be researched is whether the symbol alone, without the words, is understood by road users.

- Do Not Pass – The Do Not Pass sign may be used in addition to pavement markings to emphasize the restriction on passing. The MUTCD designation is R4-1. The 2008 NPA proposed to add a symbol sign that could be used as an alternative to the both the word message Do Not Pass sign. The symbol sign, which is similar to the Canadian MUTCD standard sign which is based on European symbols for this message, shows two cars next to each other within a red circle and a diagonal red slash through the car on the left. The FHWA decided not to adopt this symbol sign, because many State DOTs submitted comments with concerns that many drivers would not understand the meaning of the sign. Additionally, the NO PASSING ZONE warning pennant can be used to indicate locations where passing is not allowedThe FHWA decided that more research is needed regarding human interactions with the symbol before weighing options for the particular symbol sign.
- Electric Vehicle Charging Station – The purpose of the Electric Vehicle Charging sign is to inform drivers that an Electric Vehicle Charging Center is ahead. The 2003 MUTCD has a symbol sign showing a gas pump with the letters 'EV" superimposed on it and designates it as D9-11b, and the 2009 MUTCD has both the symbol sign and an optional educational word message plaque, D9-11bP. There have been no studies of driver comprehension of the existing symbol or several other symbols that various agencies have proposed.

- Fallen Rocks – The Fallen Rocks sign is to be used in advance of an area that is adjacent to a hillside, mountain, or cliff where rocks frequently fall onto the roadway. The 2008 NPA proposed a symbol sign with an educational word message plaque below it. Currently Canada, Mexico, and European standards use a symbol sign to convey the message of fallen rocks. The Mexican symbol sign that was proposed was not supported by the NCUTCD because they felt that it would not be understood by drivers and that a word sign would be much more effective. The FHWA decided to adopt only a word message sign in the 2009 MUTCD, which designates the sign as W8-14, until the symbol can undergo human factors study. W. Scott Wainwright discusses in his Sign Synthesis that the most common signs that states use to warn of rocks falling (or already fallen) are text signs, and he recommends a re-evaluation of the Canadian and Mexican symbol signs with an educational word message plaque "Falling Rocks" if needed.

- Flagger Ahead – The Flagger symbol sign is used in advance of any point where a flagger is stationed to control road users. Both the 2003 and 2009 MUTCD include options that a distance legend may be added on a supplemental plaque. The MUTCD also states that a word message sign FLAGGER can be substituted for symbol. The 2003 MUTCD designated the flagger symbol as W20-7a, while the 2009 MUTCD designates it as W20-7 with W20-7a as the alternative legend sign using a word message.

- Maximum Width – The purpose of this sign is to warn drivers that the roadway ahead has a maximum width and that vehicles exceeding that dimension will not "fit", somewhat analogous to low horizontal clearance warnings. Currently there are no proposed or adopted signs for this message in either the 2003 or 2009 MUTCD. The Sign Synthesis found several potential symbol signs that are in use.

- No Left Turn Ahead – The purpose of the No Left Turn Ahead symbol sign is to give drivers an advance warning that the left turn movement is prohibited at the upcoming intersection. The concept of this sign is similar to that of other advance warnings of downstream regulations, such as the symbolic Stop Ahead and symbolic Reduced Speed Limit Ahead signs. The 2003 and 2009 MUTCD have neither proposed nor adopted a sign for this message.

- Railroad Crossing on Leg of Roundabout – The intended purpose of this sign is to inform road users that there is a railroad crossing on one of the legs of the upcoming roundabout and to exercise caution if they are travelling that direction. Currently there have been no proposed or adopted signs for this message in either the 2003 or 2009 MUTCD.

- Cross Street Preferential Lane Warning Signs – The intended purpose of the Cross Street Preferential Lane Warning signs is to give an advance warning that the upcoming cross street has an HOV lane or some other restricted lane and that general purpose right turning traffic into that cross street needs to avoid turning into the restricted lane. This sign is not included in either the 2003 or 2009 MUTCD. It is not discussed in the Sign Synthesis, but that report does include pictures of the symbol signs that have been used for this purpose in some jurisdictions.

- Road Narrows – The Road Narrows sign should be used in advance of a transition on two-lane roads where the pavement width is reduced abruptly to a width such that vehicles traveling in opposite directions cannot simultaneously travel through the narrow portion of the roadway without reducing speed. In the 2000 and earlier editions of the MUTCD, there were symbolic versions of this sign, but the symbols were removed starting with the 2003 edition due to poor road user comprehension of the symbols. The Road Narrows sign is mentioned in W. Scott Wainwright's Sign Synthesis. He says that multiple states have variations in the messages and sign designs. He recommended that a single uniform sign design should be selected and used in advance of the condition and along the road sections with the narrowed features, and a maximum width sign should be used to warn of the actual width.

- Low Shoulder Warning Signs – The purpose of the various Low Shoulder Warning signs is to warn drivers that there is some kind of change in elevation between the travel lanes and the shoulder, and that they should take extra caution to not drive off of the roadway onto the shoulder. The 2009 MUTCD includes the W8-9 LOW SHOULDER word message sign and the W8-17 symbolic Shoulder Drop-Off sign with a W8-17P word message educational plaque. The 2009 MUTCD states that the W8-9 LOW SHOULDER sign should be used where the elevation difference between the travel lane and the shoulder is less than 3 inches, while the W8-17 symbolic shoulder drop-off sign should be used where the elevation difference exceeds 3 inches. There has not been research to determine whether drivers understand the symbolic sign or whether they understand the difference in severity of elevation difference that is intended to be communicated by the two different signs.

- Survey Crew - The purpose of the Survey Crew sign is to warn drivers of surveying crews working in or adjacent to the roadway. The 2003 MUTCD and 2009 MUTCD designate the survey crew word legend sign as W21-6. No known symbol has been proposed or adopted in the MUTCD for this sign.

- Trolley Crossing Advance Warning– The purpose of this sign is to warn drivers that there is a trolley crossing ahead. There have been no proposed or adopted signs in either the 2003 or 2009 MUTCD. The Signs Synthesis found several signs that are being used for this purpose by some jurisdictions.

- Uneven Lanes – The uneven lanes sign should be used during operations that create a difference in elevation between adjacent lanes that are open to travel. The 2003 MUTCD and 2009 MUTCD classify the uneven lanes sign as W8-11. The 2008 NPA proposed to use a symbol sign based on the Canadian signs described in the Signs Synthesis, with an educational word message "UNEVEN LANES" plaque to warn drivers that adjacent lanes are not level with each other. The NCUTCD commented that using a text sign would be much more effective than using a shoulder drop off sign with a supplemental uneven lanes sign below it. The FHWA decided that the symbolic shoulder drop off sign would not clearly convey an uneven roadway; therefore they decided to keep only the word message sign for the 2009 MUTCD until further human factors research could be performed to evaluate alternative symbols.

- Winery – The purpose of the Winery symbol is for use on guide signs to direct drivers to a winery. The 2003 and 2009 MUTCD have neither proposed nor adopted any sort of sign for this purpose, however there are several States that are using various symbols.

Table 1 provides several examples of symbol signs from a sample of the locales and some of the sources considered. Table 2 shows the final sign alternatives that were chosen through later discussions to be used in this study.

Table 1: Assortment of Domestic and International Symbol Signs

Sign Category	Representative Signs found through Various Sources				
Congestion Ahead					
Do Not Enter					
Do Not Pass					
Electric Vehicle Charging Station					
Fallen Rocks					

Sign Category	Representative Signs found through Various Sources				
Flagger Ahead					
Maximum Width					
No Left Turn Ahead					
Road Narrows					
Low Shoulder Warning Signs	 Alberta, Canada				
Survey Crew					

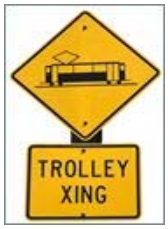
Sign Category	Representative Signs found through Various Sources				
Trolley Crossing					
Uneven Lanes	 Ontario, Can.: TC-24 (uneven lanes)				
Winery					

Table 2: Sign Alternatives Selected for Evaluation

Sign Category	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
Combination Horizontal Alignment / Advisory Speed	 36”x36”	 36”x36”	 36”x36”	 36”x36”	 36”x36”
Congestion Ahead	 36”x36”	 36”x36”	 36”x36”	None	None
Do Not Enter	 24”x24”	 24”x24”	None	None	None
Do Not Pass	 24”x24”	 36”x48”	None	None	None
Electric Vehicle Charging Station	 24”x24”	 24”x24”	 24”x24”	 24”x24”	None
Fallen Rocks	 36”x36”	 36”x36”	 36”x36”	None	None
Flagger Ahead	 36”x36”	 36”x36”	 36”x36”	None	None
Maximum Width	 36”x36”	 36”x36”	None	None	None

Sign Category	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
No Left Turn Ahead	 36”x36”	None	None	None	None
Railroad Crossing on Leg of Roundabout	 36”x36”	None	None	None	None
Cross Street Preferential Lane Warning Signs	 36”x36”	 36”x36”	None	None	None
Road Narrows	 36”x36”	 36”x36”	None	None	None
Low Shoulder Warning Signs	 36”x36”	 36”x36”	 36”x36”	 36”x36”	None
Survey Crew	 36”x36”	None	None	None	None
Trolley Crossing	 36”x36”	 36”x36”	None	None	None
Uneven Lanes	 36”x36”	 36”x36”	None	None	None
Winery	 24”x24”	 24”x24”	None	None	None

RESEARCH METHOD

RESEARCH DESIGN

The research was conducted at the Turner Fairbank Highway Research Center in the Highway Sign Simulator. In the Sign Simulator, software was used in conjunction with a projector to display the images of highway signs onto a frosted glass screen. Signs were evaluated for comprehension and legibility. The software used for legibility distance testing was designed to gradually increase the size of the sign, emulating how that sign would appear when starting from a specified distance and driving toward the sign. Sign size, driving speed, and start distance could all be manipulated to make the representation as accurate as possible. The size of the sign when it became legible could then be translated into distance. Both the software for comprehension and for legibility electronically collected the required data and saved output data files for analysis.

Comprehension

The first portion of the study evaluated comprehension of each sign alternative in the different sign categories. This was a three stage process in which participants provided open-ended responses, multiple choice responses and rankings of the signs. The open-ended and multiple choice sections were a between subjects design in which participants only saw one sign alternative in each sign category. For each section, participants were only shown one sign at a time, and the sign remained on the screen for as long as they needed to provide their response. In the ranking section, participants were shown all sign alternatives for a given category and asked to rank each sign on how well they think it shows the intended meaning of the sign. Participants would complete all three sections for a given sign category before moving on to the next category; i.e., complete open-ended, multiple choice and rankings for "Do Not Enter" before moving on to "Congestion Ahead".

Open-Ended

When a first sign appeared on the screen, participants were asked, "What does this sign mean to you?" They were to respond aloud with what they thought the sign meant, or what they thought it was trying to tell them. A researcher transcribed their responses.

They were then asked a follow-up question such as "What action should you take?", "How would this sign change your behavior?", or "Where would you expect to see a sign like this?" The follow up question varied depending on the type of sign and which question was most applicable. The goal of these questions was to further clarify their understanding based on their response to the first question, or to inquire about a different aspect of the sign. For example, a "Do Not Pass" text sign may elicit a response to the first question such as "do not pass when you see this sign". The follow up question requires the participant to give more detail, possibly divulging that they thought it meant not to continue past this point on the road, rather than the intended meaning, do not overtake and pass other vehicles.

Multiple Choice

Upon completion of the open-ended questions, participants were asked to choose from among three or four definitions (only one of which was correct) the option that *best* describes the meaning of the sign.

Ranking

Before the ranking section, participants were shown all sign options for the current sign category (e.g. if they had just seen the "Congestion Ahead" text sign option for the open-ended and multiple choice sections, they would now be shown all three sign alternatives in the Congestion Ahead sign category that is shown in table 2. Participants were told the intended meaning of the signs, given time to look over all of the sign alternatives, and then ranked each alternative on how well it would work to illustrate the intended meaning. The scale ranged from 1-7, where 1 represented "would not work at all", 4 represented "might work" and 7 represented "would work very well". They were asked to rank each sign individually rather than order them; i.e., two signs may have the same ranking, they should not order them from best to worst and vice versa.

Legibility

The Sign Simulator was used to test the legibility distance – the maximum distance at which the participant can read text or decipher the elements of the sign. For the legibility distance evaluation, participants were presented each sign option of every sign category, totaling to 41 test signs. There were also 12 distracter signs added to counteract immediate recall from the comprehension testing. The signs were added to the scenario to minimize guesses due to participants recalling signs from comprehension testing. The distracter signs included: Stop, Yield, Railroad Crossing, Fire Station, Slower Traffic Keep Right, No U-turn, Deer Crossing, Intersection, Hospital, Road Work, Airport, and Dead End. All 53 signs were randomized, with the exception of "Stop" "Yield" and "Railroad Crossing" which were always presented first as practice signs.

For the test, each sign was shown one at a time. The entire projection screen was black apart from the sign. Each sign presentation began at a simulated distance of 1000 feet (304.8 meters). The sign then expanded in size to simulate an approach speed of 35 miles per hour. Participants were instructed to keep their eyes on the sign, and to push a button on the table in front of them when they could identify the sign. When the button was pressed, the projection screen went blank.

The instructions emphasized that this was not a comprehension test. Participants were asked to push the button immediately when they could make out the sign. They were instructed to push the button first, after which they would have time to describe the sign.

After the participant described what the sign was, the researcher determined if their response was correct or incorrect. Correctness was deemed to be anything that confirmed that the sign was legible to them. If the participant was correct, a new trial was begun with a different sign. If the response was incorrect, the same sign reappeared and continued to increase in size from the size it was when the button was pressed and the participant was to press the button again when the sign could be correctly identified. If the sign size reached the full screen without a correct response, the trial was terminated and the next trial begun.

PARTICIPANTS

Participants were recruited from the Washington, DC metropolitan area. Of the 96 participants, half were between 19 and 56 years of age (mean = 37), and half were 57 years of age or older. Each age grouping consisted of equal numbers of males and females. All participants possessed a valid driver's license and passed a vision screening test with a minimum 20/40 acuity in at least one eye (corrected if necessary). Participants were paid $45 upon completion.

RESULTS

The results for each message category are presented separately. All tests were evaluated with maximum probability of Type I error of 0.05.

COMBINATION HORIZONTAL ALIGNMENT / ADVISORY SPEED

Comprehension

The research team evaluated five signs that might be appropriate for warning of the location of an alignment change combined with an advisory speed. In each of these signs, an arrow was used to indicate the nature of the alignment changes, and a number represented the recommended safe speed for this alignment change. The five alternatives and their respective mean comprehension scores based on open-ended responses are shown in Table 3.
The open-ended responses of the participants were evaluated on whether or not they reflected a correct understanding of the sign. Correct responses had to reflect correct understanding of the arrow and of the number. However, participants did not necessarily have to indicate that the sign was located at the point of the alignment change to be scored as a correct answer. Fisher's Exact Test indicated that comprehension varied significantly by sign alternative ($p < .001$). Analyses comparing two proportions were performed to determine the differences in comprehension between the specific sign alternatives. Alternative 1 was significantly less well comprehended than alternatives 2, 3 and 5 ($Z = 2.57$, $p = .005$). There were no other statistically significant differences between pairs of signs.

Of the incorrect responses for Alternative 1, all participants interpreted the number as a representation of distance to the alignment change (10 miles or 10 feet away). Of the incorrect responses for Alternative 4, 66.7% thought the number represented the degree, or sharpness, of the curve, and 33.3% interpreted the sign as meaning the driver must go 35mph around the truck. While 81.3% of participants were correct in their understanding of the arrow and the number, 30.8% of those who were correct thought the recommended safe speed for the curve applied to trucks only.

The alignment sign alternatives each depict a different message, therefore the multiple choice and ranking sections were not used to assess comprehension for this sign group.

Table 3: Comprehension Results for Combination Horizontal Alignment / Advisory Speed Signs

Sign Alternative	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
					
Open-Ended Response					
Understood	56.3%	100%	100%	81.3%	100%

Legibility Distance

The mean legibility distances were 427ft (130.24m), 417ft (127.19m), 404ft (123.22m), 389ft (118.65m), and 405ft (123.53m), respectively for the Alternative 1, Alternative 2, Alternative 3, Alternative 4, and Alternative 5. Because each sign indicates a different message, an analysis to compare the five legibility distances is not necessarily meaningful. The figure below indicates the mean distance and the 95% confidence interval for each alternative.

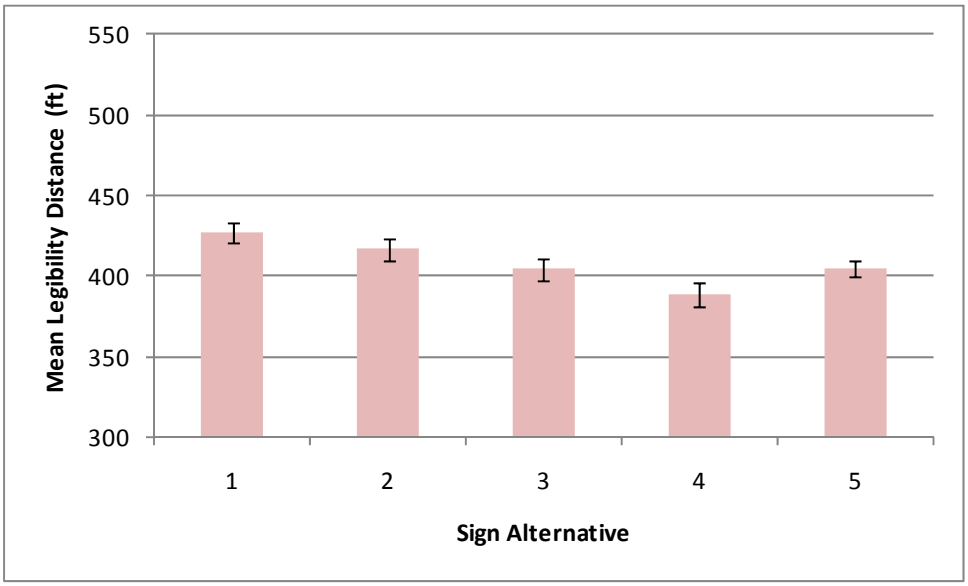


Figure 1: Mean Distances for Combination Horizontal Alignment / Advisory Speed Signs

CONGESTION AHEAD

Comprehension

Three signs that might be appropriate to indicate Congestion Ahead were evaluated. The three alternatives and their respective comprehension scores are shown in Table 4.

The open-ended responses were rated on how well participants understood that there may be congestion ahead. For Alternative 2, they were rated on how well they understood that drivers should be prepared to stop due to something going on in the roadway ahead. For this alternative only, they were not expected to report that it was specifically due to congestion in the roadway ahead. Fisher's Exact Test indicated that comprehension varied significantly by sign alternative ($p < .001$).

The multiple choice response that best describes the meaning of these signs is "Congestion Ahead". 100% of participants chose this response for Alternative 1, 75% for Alternative 2 and 93.8% for Alternative 3. The remaining 25% for Alternative 2 chose the response "Vehicle Checkpoint Ahead". As noted above, participants were not expected to identify the specific reasoning that they should "be prepared to stop" for Alternative 2 as it gives no indication that this would be due to congestion.

The mean rankings of Alternative 1 (*M*=6.68), Alternative 2 (*M*=5.59) and Alternative 3 (*M*=3.45) imply that participants tend to consider Alternatives 1 and 2 as more effective in illustrating the intended meaning of the sign.

Table 4: Comprehension Results for Congestion Ahead Signs

Sign Alternative	**Alternative 1**	**Alternative 2**	**Alternative 3**
			
Open-Ended Response			
Understood	100%	100%	78.10%
Multiple Choice Response			
Parked Cars on the Side of the Road	0	0	3.1%
Passing Zone	0	0	3.1%
Congestion Ahead	100%	75%	93.8%
Vehicle Checkpoint Ahead	0	25%	0
Ranking			
1 - Would Not Work at All	0	2%	16%
2	0	4%	15%
3	0	4%	17%
4 - Might Work	2%	10%	30%
5	3%	17%	13%
6	20%	26%	6%
7 - Would Work Very Well	75%	36%	4%

Legibility Distance

There were three congestion signs tested for legibility distance. The mean legibility distances and the 95 percentile confidence limits are shown in figure 2. Repeated measures ANOVA showed that the mean legibility distances differed significantly $F(1.62) = 32.24$, $p < .001$. The legend size in "BE PREPARED TO STOP" at approximately 5" (13 cm) is larger than "CONGESTION AHEAD" at approximately 4" (10 cm) which makes the sign more legible from farther distances. The symbol used in Alternative 3 resulted in lower mean legibility distance values compared to Alternative 2.

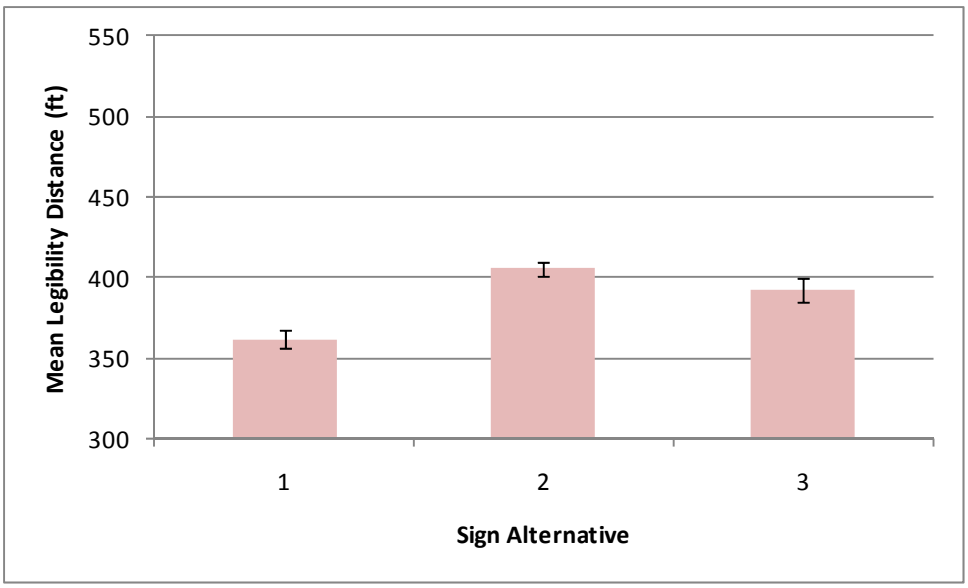


Figure 2: Mean Distances for Congestion Ahead Signs

DO NOT ENTER

Comprehension

Two sign alternatives to show Do Not Enter were identified. The two alternatives and results of the comprehension evaluations are shown in Table 5.

An analysis comparing two proportions showed that comprehension for Alternative 2 is significantly higher than comprehension for Alternative 1, ($Z = 4.22$, $p < .001$). While both alternatives performed well in the multiple choice questions, Alternative 2 produced 100% correct responses in this section.

The multiple choice response that best describes the meaning of these signs is "Do Not Enter". 68.8% of participants chose this response for Alternative 1, and 100% chose this for Alternative 2. The remaining 16.6% for Alternative 1 chose thought the version without text could mean "Stop" or "Yield".

The mean rankings of Alternative 1 (M=3.79) and Alternative 2 (M=6.97) imply that participants tend to consider Alternative 2 as more effective in illustrating the intended meaning of the sign.

Table 5: Comprehension Results for Do Not Enter Signs

Sign Alternative	Alternative 1	Alternative 2
		
Open-Ended Response		
Understood	68.8%	100%
Multiple Choice Response		
Yield	8.3%	0
Do Not Enter	83.3%	100%
Stop	8.3%	0
Enter	0	0
Ranking		
1 - Would Not Work at All	21%	0
2	6%	0
3	15%	0
4 - Might Work	20%	0
5	19%	0
6	9%	3%
7 - Would Work Very Well	10%	97%

Legibility Distance

As shown in Figure 3, the mean legibility distance for Alternative 1 was significantly longer than for Alternative 2, $t(93) = 2.136$, $p = .035$. The only difference in the two signs is the legend "DO NOT ENTER".

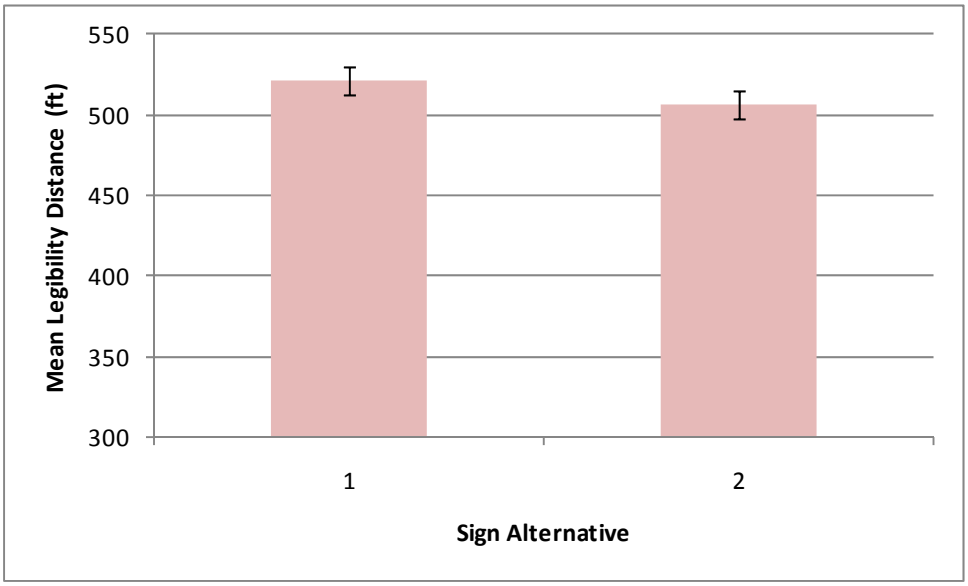


Figure 3: Mean Distances for Do Not Enter Signs

DO NOT PASS

Comprehension

Two sign alternatives to show Do Not Pass were evaluated. The comprehension findings are shown in Table 6.

Comprehension of Alternative 2 was significantly greater than comprehension for Alternative 1, ($Z = 5.19$, $p < .001$). The only participant who did not comprehend the meaning of Alternative 2 interpreted the sign as meaning that drivers should not drive past that point on the current road. The multiple choice response that best describes the meaning of these signs is "Do Not Pass". 62.5% of participants chose this response for Alternative 1, and 100% chose this for Alternative 2.

The mean rankings of Alternative 1 (M=3.34) and Alternative 2 (M=6.84) imply that participants tend to consider Alternative 2 as more effective in illustrating the intended meaning of the sign.

Table 6: Comprehension Results for Do Not Pass Signs

Sign Alternative	**Alternative 1**	**Alternative 2**
		
Open-Ended Response		
Understood	47.9%	97.9%
Multiple Choice Response		
Caution When Passing	6.3%	0
Do Not Pass	62.5%	100%
No Side to Side Parking	16.7%	0
Only One Lane Ahead	14.6%	0
Ranking		
1 - Would Not Work at All	24%	0
2	15%	0
3	8%	0
4 - Might Work	28%	1%
5	10%	3%
6	10%	6%
7 - Would Work Very Well	4%	90%

Legibility Distance

As shown in figure 4, the mean legibility distance for the symbol sign (Alternative 1) was significantly less than for the text alternative, $t(93) = 13.622$, $p<.001$.

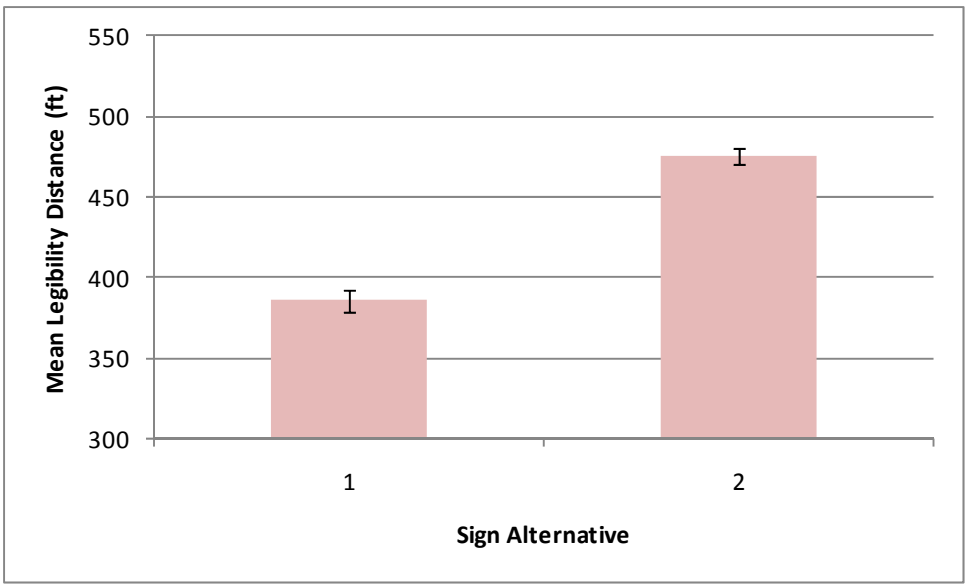


Figure 4: Mean Distances for Do Not Pass Signs

ELECTRIC VEHICLE CHARGING STATION

Comprehension

Four sign alternatives to indicate an Electric Vehicle Charging Station were evaluated. The comprehension findings are shown in Table 7.

A chi-square test of independence indicated that comprehension varies significantly by sign alternative, $\chi^2(3, N = 96) = 26.63$, $p < .001$. Analyses comparing two proportions were used to determine the differences in comprehension between specific sign alternatives. Post hoc tests showed that the second alternative was better comprehended than the other three alternatives.

Of all the incorrect responses for Alternative 1, 100% interpreted the sign as a gas station sign. Of the incorrect responses for Alternative 2, 42.9% interpreted the sign to be a gas station or rest stop, and 28.6% had no idea what the sign could mean. Of the incorrect responses for Alternative 3, 38.9% interpreted this alternative as a sign indicating a location where you can repair or pull over for car or battery problems, 27.8% thought it had to do with emergency vehicles (either you are near a fire station or hospital where these vehicles often drive or indicating parking for emergency vehicles), and 16.7% had no idea. Of the incorrect responses for Alternative 4, 50% interpreted it as a sign for emergency vehicles (Lane or road for emergency vehicles only, emergency facility nearby, or parking space for emergency vehicles only), 31.8% had no idea, and 13.6% thought it was a special lane that only electric vehicles should drive in.

The multiple choice response that best describes the meaning of these signs is “Electric Vehicle Charging Station”. 70.8%% of participants chose this response for Alternative 1, 87.5% for Alternative 2, 91.7% for Alternative 3 and 100% for Alternative 4.

The mean rankings imply that participants tend to consider Alternative 2 as more effective in illustrating the intended meaning of the sign.

Table 7: Comprehension Results for Electric Vehicle Charging Station Signs

Sign Alternative	Alternative 1	Alternative 2	Alternative 3	Alternative 4
				
Open-Ended Response				
Understood	16.7%	70.8%	25%	8.3%
Multiple Choice Response				
Electronic Device Charging Station	0	8.3%	4.2%	0
Gas Station	25%	4.2%	4.2%	0
Tire Pressure Station	4.2%	0	0	0
Electric Vehicle Charging Station	70.8%	87.5%	91.7%	100%
Ranking				
1 - Would Not Work at All	10%	5%	15%	16%
2	8%	0	13%	9%
3	16%	0	15%	17%
4 - Might Work	30%	7%	28%	34%
5	14%	9%	10%	14%
6	10%	23%	11%	8%
7 - Would Work Very Well	11%	55%	8%	2%

Legibility Distance

Mean legibility distances and 95 percent confidence limits are shown in Figure 5. Repeated measures ANOVA showed that the legibility distances of the different sign alternatives differed significantly $F(2.51) = 9.51$, $p < .001$. Alternative 1 which is currently in the MUTCD performed the best, presumably because of its relatively simple design. Alternative 3 did not perform as well, perhaps because of the narrow stroke widths of the graphics used to depict the battery.

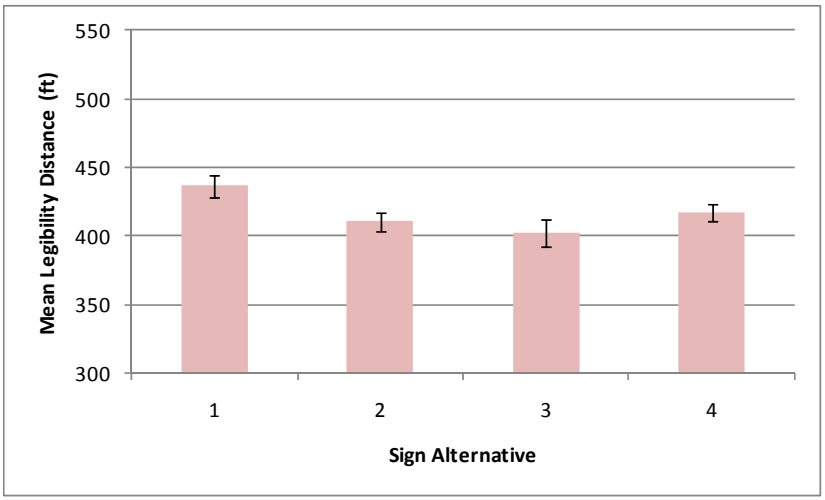


Figure 5: Mean Distances for Electric Vehicle Charging Station Signs

FALLEN ROCKS

Comprehension

Three sign alternatives were evaluated to indicate that there may be fallen rocks in the roadway ahead. For this study, we did not take into consideration the fact that the rocks may be falling versus have already fallen. The comprehension findings are shown in Table 8.

There were no significant differences in comprehension of the three alternatives ($p > .05$).

The multiple choice response that best describes the meaning of these signs is "Watch for Fallen Rocks". 100% of participants chose this response for Alternatives 1, 2 and 3.

The mean rankings imply that participants tend to rank all three alternatives similarly on how well they illustrate the intended meaning of the sign.

Table 8: Comprehension Results for Fallen Rocks Signs

Sign Alternative	**Alternative 1**	**Alternative 2**	**Alternative 3**
			
Open-Ended Response			
Understood	100%	100%	96.9%
Multiple Choice Response			
Watch for Fallen Rocks	100%	100%	100%
Watch for Broken Pieces off Building	0	0	0
Rock Climbing Area Ahead	0	0	0
Cliff Jumping Area Ahead	0	0	0
Ranking			
1 - Would Not Work at All	1%	0	5%
2	2%	1%	5%
3	1%	5%	10%
4 - Might Work	13%	6%	15%
5	13%	8%	22%
6	24%	21%	24%
7 - Would Work Very Well	47%	58%	19%

Legibility Distance

The results of repeated measures ANOVA indicate that the legibility distances of the different sign alternatives differed significantly $F(2) = 21.04$, $p<.001$. There were no significant differences between Alternatives 1 and 2 at $\alpha = .05$ level; however, both are significantly

different from Alternative 3. The figure below indicates the mean distance and the 95% confidence interval for each alternative.

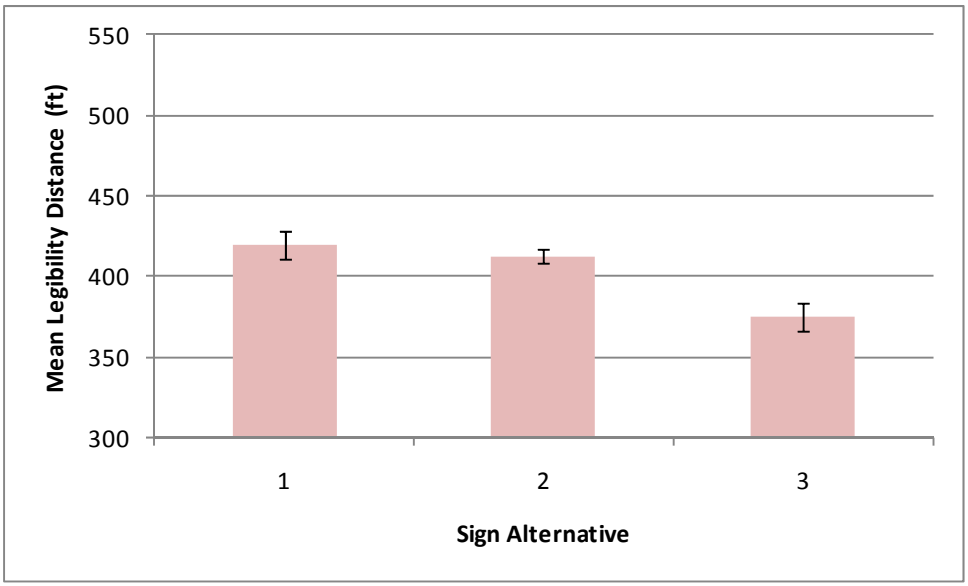


Figure 6: Mean Distances for Fallen Rocks Signs

FLAGGER AHEAD

Comprehension

Three sign alternatives were evaluated to indicate that there is a flagger ahead. The comprehension findings are shown in Table 9.

Fisher's Exact Test indicated no significant differences in comprehension between sign alternatives, $p = 0.771$.

The multiple choice response that best describes the meaning of these signs is "Flagger Ahead". 71.8% of participants chose this response for Alternative 1, 90.6% chose this response for Alternative 2 and 93.8% chose this response for Alternative 3. For all three alternatives, the only other response chosen was "Crossing Guard Ahead".

The mean rankings imply that participants tend to rank all three alternatives similarly on how well they illustrate the intended meaning of the sign.

Table 9: Comprehension Results for Flagger Ahead Signs

Sign Alternative	Alternative 1	Alternative 2	Alternative 3
			
Open-Ended Response			
Understood	96.9%	93.8%	100%
Multiple Choice Response			
School Zone Ahead	0	0	0
Flagger Ahead	78.1%	90.6%	93.8%
Crossing Guard Ahead	21.9%	9.4%	6.3%
Information Center Ahead	0	0	0
Ranking			
1 - Would Not Work at All	1%	0	0
2	2%	1%	1%
3	1%	1%	6%
4 - Might Work	7%	17%	5%
5	13%	15%	14%
6	31%	18%	19%
7 - Would Work Very Well	45%	49%	55%

Legibility Distance

The results of a repeated measures ANOVA show that the legibility distances of the different sign alternatives differed significantly $F(2) = 122.61$, $p<.001$. Both of the symbols (Alternative 1 and Alternative 2) performed better than the text-based sign (Alternative 3) and the current standard sign (Alternative 2) performed better than the alternative symbol (Alternative 1). The figure below indicates the mean distance and the 95% confidence interval for each alternative.

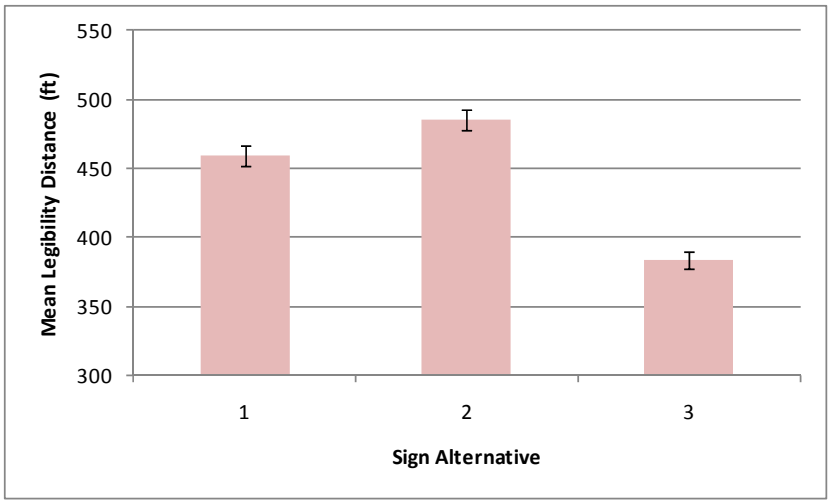


Figure 7: Mean Distances for Flagger Ahead Signs

MAXIMUM WIDTH

Comprehension

The research team evaluated two signs to show Maximum Width. The two alternatives and results of the comprehension evaluations are shown in Table 10.

An analysis comparing two proportions show no significant difference in comprehension between Alternative 1 and Alternative 2 at the $\alpha = .05$ level.

While the majority of participants responded correctly in understanding that this sign shows maximum width, there was some variation on what this width was referring to. From the correct responses for Alternative 1, 26.8% said width of the road, 19.5% said width of the lane, 17.1% said width of an upcoming tunnel, overpass or other passageway, and 36.6% were vague on what this width was, but knew that their vehicle should not be wider than this. For the correct responses for Alternative 2, 26.1% said width of the road, 15.2% said width of the lane, 15.2% said width of an upcoming tunnel, overpass or other passageway, and 43.5% were vague on what this width was, but knew that their vehicle should not be wider than this.

The multiple choice response that best describes the meaning of these signs is "Maximum Roadway Width". 79.2% of participants chose this response for Alternative 1 and 87.5% of participants chose this for Alternative 2. The remaining participants either selected "Minimum Roadway Width" or "Tunnel Clearance". "Tunnel Clearance" may be an appropriate response since in many cases, a tunnel would restrict roadway width; however since we asked participants to choose the BEST answer, the response desired was "Maximum Roadway Width".

The mean rankings of Alternative 1 (M=4.51) and Alternative 2 (M=6.60) show that participants tend to rank Alternative 2 higher on how well it illustrates the intended meaning of the sign.

Table 10: Comprehension Results for Maximum Width Signs

Sign Alternative	Alternative 1	Alternative 2
		
Open-Ended Response		
Understood	87.5%	95.8%
Multiple Choice Response		
Minimum Roadway Width	8.3%	2.1%
Tunnel Clearance	12.5%	10.4%
Maximum Roadway Width	79.2%	87.5%
Parking Clearance	0	0
Ranking		
1 - Would Not Work at All	6%	0
2	10%	0
3	6%	0
4 - Might Work	22%	2%
5	27%	7%
6	15%	19%
7 - Would Work Very Well	14%	72%

Legibility Distance

The mean legibility distance for Alternative 2 was significantly greater than for Alternative 1, $t(93) = 2.765$, $p=.007$. Alternative 2 used larger text than Alternative 1 which may account for the difference. The figure below indicates the mean distance and the 95% confidence interval for each alternative.

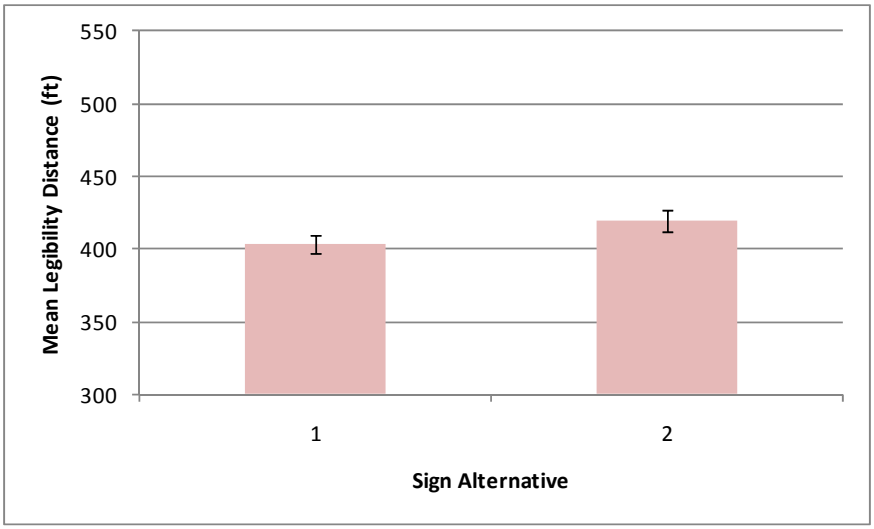


Figure 8: Mean Distances for Maximum Width Signs

NO LEFT TURN AHEAD

Comprehension

The research team evaluated one sign to indicate No Left Turn Ahead. The results of the comprehension evaluations are shown in Table 11.

Results of the open-ended response show that 40.6% of participants understood the meaning of the No Left Turn Ahead sign. Participants who did not understand the meaning of the sign tended to interpret it as meaning "No left turn, go straight ahead only". For the multiple choice question, 81.3% of participants responded correctly and the average sign ranking was 5.85.

The multiple choice response that best describes the meaning of this signs is "No Left Turn Ahead". 81.3% of participants chose this response, while the remaining 18.8% selected "No Left Turn".

The mean ranking of this sign (*M*=5.85) implies that participants think this sign would work fairly well to illustrate the intended meaning.

Table 11: Comprehension Results for No Left Turn Ahead Signs

Sign Alternative	**Alternative 1**
	
Open-Ended Response	
Understood	40.6%
Multiple Choice Response	
No Left Turn Ahead	81.3%
No Left Turn	18.8%
No Right Turn Ahead	0
No Right Turn	0
Ranking	
1 - Would Not Work at All	1%
2	3%
3	2%
4 - Might Work	9%
5	15%
6	27%
7 - Would Work Very Well	43%

Legibility Distance

The mean legibility distance for the No Left Turn Ahead sign was 410ft (125.05m) with a standard error of 5.98.

RAILROAD CROSSING ON LEG OF ROUNDABOUT

Comprehension

The research team evaluated one sign intended to indicate a railroad crossing at the right leg of the roundabout. The results of the comprehension evaluations are shown in Table 14.

Results of the open-ended response show that 90.6% of participants understood the meaning of the Roundabout Railroad Crossing sign.

The multiple choice response that best describes the meaning of this sign is "Railroad Crossing at the Right Leg of the Roundabout". 90.6% of participants chose this response.

The ranking of Alternative 1 implies that participants felt that the sign would work to illustrate its intended meaning.

Table 12: Comprehension Results for Railroad Crossing on Leg of Roundabout Sign

Sign Alternative	**Alternative 1**
	
Open-Ended Response	
Understood	90.6%
Multiple Choice Response	
Train Circle Ahead	2.1%
Roundabout Crossing	7.3%
Railroad Crossing at the Right Leg of the Roundabout	90.6%
Pedestrian Crossing at the Right Leg of the Roundabout	0
Ranking	
1 - Would Not Work at All	1%
2	1%
3	0
4 - Might Work	15%
5	16%
6	28%
7 - Would Work Very Well	40%

Legibility Distance

The mean legibility distance for the Railroad Crossing on Leg of Roundabout sign was 423ft (129.02m) with a standard error of 7.47.

CROSS STREET PREFERENTIAL LANE WARNING SIGNS

Comprehension

The research team evaluated two signs to show Cross Street Preferential Lanes. The open-ended responses were scored on two levels of comprehension. The first level of comprehension (General Restriction) was based on whether or not the participant understood that there was some sort of restriction. This could include HOV, bike lane, bus lane, or any combination of the three. The second level of comprehension (HOV Restriction) was based on whether or not the participant understood that it is specifically an HOV restriction and no other type of restriction. The two alternatives and results of the comprehension evaluations are shown in Table 12.

An analysis comparing two proportions was used to determine the differences in comprehension between the two alternatives for each level of comprehension. For the first level, General Restriction, there was no significant difference in comprehension between the two sign alternatives ($\alpha = .05$ level). For the second level, Alternative 1 had significantly higher comprehension than Alternative 2 ($Z = 2.68$, $p = .007$).

The multiple choice response that best describes the meaning of these signs is “Right Turns are Limited by HOV Lanes”. 66.7% of participants chose this response for Alternative 1 and 52.1% chose this response for Alternative 2. The authors believe that the word choice used in the multiple choice responses may not have been clear to participants. However, the results are not much different from the results obtained from the Open-Ended responses.

The mean rankings of Alternative 1 (M=4.26) and Alternative 2 (M=4.04) imply that participants generally ranked both alternatives evenly and on average, thought these alternatives might work to show the intended meaning.

Table 13: Comprehension Results for Cross Street Preferential Lane Warning Signs

Sign Alternative	Alternative 1	Alternative 2
		
Open-Ended Response		
Understood General Restriction (bike/bus/HOV)	75%	62.5%
Understood HOV restriction	56.3%	29.2%
Multiple Choice Response		
Right Turns are Limited by HOV Lanes	66.7%	52.1%
Bicycle Lane Only in Specified Lane	8.3%	25%
Right Turns Allowed	22.9%	22.9%
HOV Open in All Lanes	2.1%	0
Ranking		
1 - Would Not Work at All	16%	10%
2	8%	11%
3	7%	18%
4 - Might Work	19%	21%
5	18%	15%
6	18%	14%
7 - Would Work Very Well	15%	11%

Legibility Distance

The mean legibility distance was 357ft (108.89m) for Alternative 1 and 341ft (104.01m) for Alternative 2. Since the two signs indicate a different message, an analysis to compare the legibility distances is not practical.

ROAD NARROWS

Comprehension

The research team evaluated two signs to show Road Narrows. The two alternatives and results of the comprehension evaluations are shown in Table 13.

An analysis comparing two proportions showed that Alternative 2 has significantly higher comprehension than Alternative 1, ($Z = 5.01$, $p < .001$).

The multiple choice response that best describes the meaning of these signs is “Road Narrows”. 58.3% of participants chose this response for Alternative 1 and 91.7% chose this response for Alternative 2.

The rankings imply that participants tend to rank Alternative 2 higher than Alternative 1 on how well they illustrate the intended meaning of the sign.

Table 14: Comprehension Results for Road Narrows Signs

Sign Alternative	Alternative 1	Alternative 2
		
Open-Ended Response		
Understood	35.4%	85.4%
Multiple Choice Response		
Merging Lanes	12.5%	4.2%
Road Narrows	58.3%	91.7%
Roadway Merges to One Lane	20.8%	4.2%
Median Ends	8.3%	0
Ranking		
1 - Would Not Work at All	7%	0
2	5%	0
3	6%	1%
4 - Might Work	22%	2%
5	22%	4%
6	13%	20%
7 - Would Work Very Well	25%	73%

Legibility Distance

The mean legibility distance of Alternative 1 was significantly higher than for Alternative 2, $t(93) = 11.048$, $p<.001$. The figure below indicates the mean distance and the 95% confidence interval for each alternative.

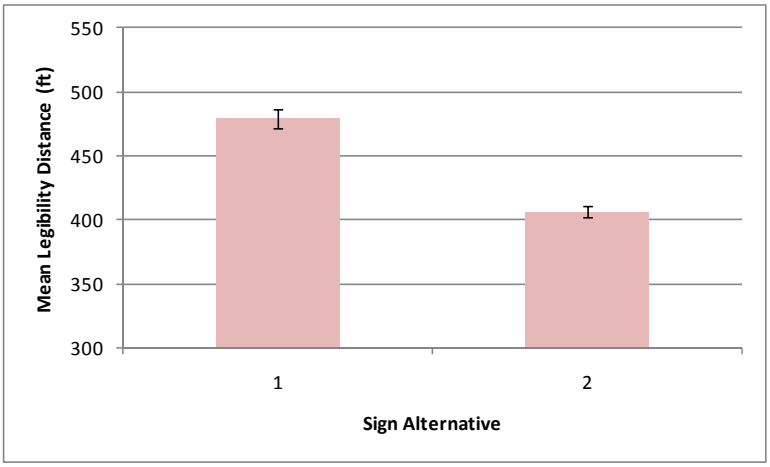


Figure 9: Mean Distances for Road Narrows Signs

LOW SHOULDER WARNING SIGNS

Comprehension

The research team evaluated four alternative designs to indicate hazards due to a change in elevation between the travel lanes and the shoulder. The results of the comprehension evaluations are shown in Table 15.

A chi-square test of independence indicated that comprehension varied significantly by sign alternative, χ^2 (3, N = 96) = 58.15, p < .001. Post hoc analyses comparing two proportions showed that alternatives 1 and 2 were not significantly different from each other and were significantly different from alternatives 3 and 4, which were not significantly different from each other.

As a follow-up, all participants were asked if they think there is a difference between "Shoulder Drop-off" and "Low Shoulder". Of the 55.2% who said there is a difference between them, the majority (84.9%) attributed the difference to the level of severity, saying that a Shoulder Drop-Off is more severe than a Low Shoulder. Other explanations included:

- Presence of guardrail – Low Shoulder has a guardrail and Shoulder Drop-Off does not
- Distance of elevation change from road – Low Shoulder the change is right next to the road, Shoulder Drop-Off the change is farther from the road
- Material of the Shoulder – Low Shoulder has a paved shoulder; Shoulder Drop-Off has an unpaved shoulder of grass or gravel
- Meaning of Sign – Low Shoulder indicates that you should stay off the shoulder; Shoulder Drop-Off indicates that there is a change in elevation
- Do not know the difference

The multiple choice response that best describes the meaning of these signs was "There is a Change in Elevation between the Travel Lanes and the Shoulder". 95.8% of participants chose this response for Alternative 1, 95.8% chose it for Alternative 2, 20.8% chose it for Alternative 3 and 58.3% chose it for Alternative 4. All participants who did not select this meaning selected "There is a Change in Elevation between Two Travel Lanes" for all four sign alternatives.

The mean rankings imply that participants tend to rank all four alternatives similarly on how well they illustrate the intended meaning of the sign and on average think that they may work, or may work somewhat well.

Table 15: Comprehension Results for Low Shoulder Warning Signs

Sign Alternative	Alternative 1	Alternative 2	Alternative 3	Alternative 4
				
Open-Ended Response				
Understood	83.3%	91.7%	4.2%	16.7%
Multiple Choice Response				
There is a Change in Elevation between Two Travel Lanes	4.2%	4.2%	79.2%	41.7%
There is a Change in Elevation between the Travel Lanes and the Shoulder	95.8%	95.8%	20.8%	58.3%
Watch for Metal Plates in the Travel Lanes	0	0	0	0
Ranking				
1 - Would Not Work at All	2%	0	5%	8%
2	2%	3%	2%	14%
3	6%	4%	16%	11%
4 - Might Work	14%	19%	24%	27%
5	20%	10%	22%	18%
6	21%	30%	16%	15%
7 - Would Work Very Well	35%	33%	16%	7%

Legibility Distance

The results of a repeated measures ANOVA show that the legibility distances of the different sign alternatives differed significantly $F(2.36) = 38.33$, $p<.001$. There were no significant differences between Alternatives 2, 3, and 4 at $\alpha = .05$ level. Alternative 1 contains text with a shorter letter height than Alternative 2 may have been the cause of its shorter mean legibility distance. The figure below indicates the mean distance and the 95% confidence interval for each alternative.

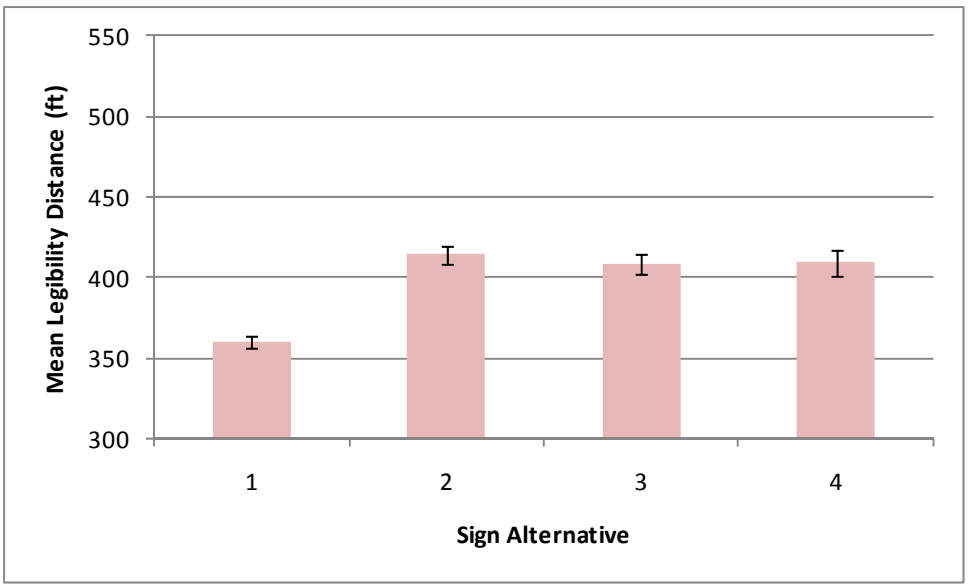


Figure 10: Mean Distances for Low Shoulder Warning Signs

SURVEY CREW

Comprehension

One sign was evaluated to illustrate Survey Crew. The comprehension findings are shown in Table 16.

Results of the open-ended response show that 92.7% of participants understood the meaning of the Survey Crew sign.

The multiple choice response that best describes the meaning of this sign is "Survey Crew Ahead". 91.7% of participants chose this response.

The mean ranking shows that participants, on average, tend to think this sign would work well or very well to illustrate the intended meaning.

Table 16: Comprehension Results for Survey Crew Sign

Sign Alternative	**Alternative 1**
	
Open-Ended Response	
Understood	92.7%
Multiple Choice Response	
Research Park	0
Scenic Overlook	8.3%
Survey Crew Ahead	91.7%
Film Studio	0
Ranking	
1 - Would Not Work at All	1%
2	2%
3	1%
4 - Might Work	9%
5	14%
6	23%
7 - Would Work Very Well	50%

Legibility Distance

The mean legibility distance for the Survey Crew sign was 409ft (124.75m) with a standard error of 5.83.

TROLLEY CROSSING

Comprehension

The research team evaluated two signs to show that there is a trolley crossing ahead. The two alternatives and results of the comprehension evaluations are shown in Table 17.

An analysis comparing two proportions showed that there is no significant difference in comprehension between Alternative 1 and Alternative 2 at the $\alpha = .05$ level.

The multiple choice response that best describes the meaning of these signs is "Trolley Crossing". 93.8% of participants chose this response for Alternative 1, and 95.8% chose it for Alternative 2.

Table 17: Comprehension Results for Trolley Crossing Signs

Sign Alternative	Alternative 1	Alternative 2
		
Open-Ended Response		
Understood	97.9%	95.8%
Multiple Choice Response		
School Bus Crossing	2.1%	0
Train Station	2.1%	4.2%
Trolley Crossing	93.8%	95.8%
Bus Station	2.1%	0
Ranking		
1 - Would Not Work at All	3%	0
2	6%	1%
3	10%	1%
4 - Might Work	24%	7%
5	27%	8%
6	21%	21%
7 - Would Work Very Well	8%	61%

Legibility Distance

The mean legibility distance of Alternative 1 was significantly higher than for Alternative 2, $t(93) = 10.181$, $p<.001$. The figure below indicates the mean distance and the 95% confidence interval for each alternative.

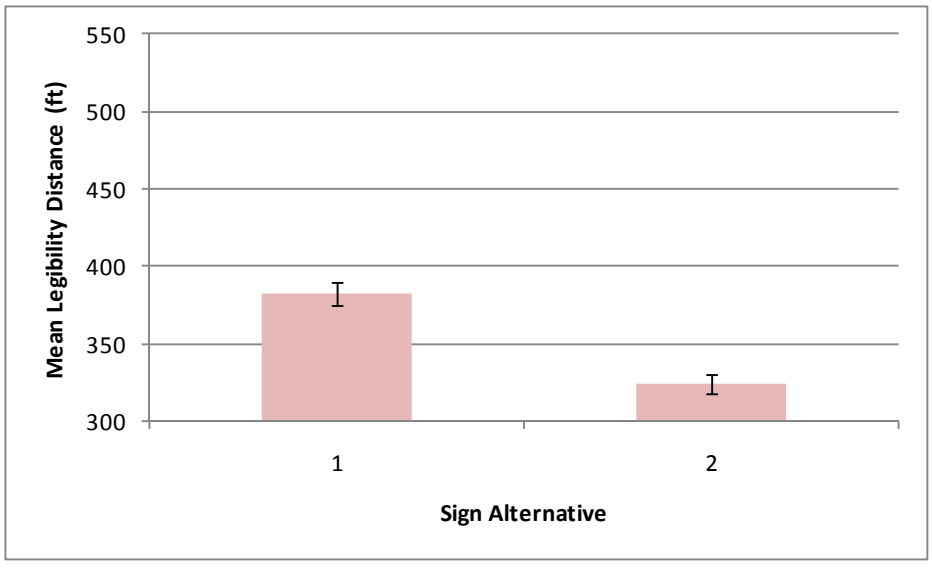


Figure 11: Mean Distances for Trolley Crossing Signs

UNEVEN LANES

Comprehension

Two signs were evaluated to illustrate that there are uneven lanes ahead. The comprehension findings are shown in Table 18.

An analysis comparing two proportions showed that Alternative 2 has significantly higher comprehension than Alternative 1 ($Z = 2.15$, $p = .032$).

The multiple choice response that best describes the meaning of these signs is "Uneven Lanes". 89.6% of participants chose this response for Alternative 1, and 97.9% chose it for Alternative 2.

The mean rankings show that participants tend to rank the alternatives similarly on how well they illustrate the intended meaning of the sign and, on average, think they would work well to show the intended meaning.

Table 18: Comprehension Results for Uneven Lanes Signs

Sign Alternative	**Alternative 1**	**Alternative 2**
		
Open-Ended Response		
Understood	66.7%	85.4%
Multiple Choice Response		
Uneven Lanes	89.6%	97.9%
Soft Shoulder	0	0
No Passing	4.2%	2.1%
Road Under Construction	6.3%	0
Ranking		
1 - Would Not Work at All	5%	4%
2	2%	6%
3	3%	4%
4 - Might Work	6%	20%
5	5%	16%
6	18%	29%
7 - Would Work Very Well	60%	21%

Legibility Distance

The mean legibility distance Alternative 1 was significantly higher than for Alternative 2, $t(94) = 4.823$, $p<.001$. The figure below indicates the mean distance and the 95% confidence interval for each alternative.

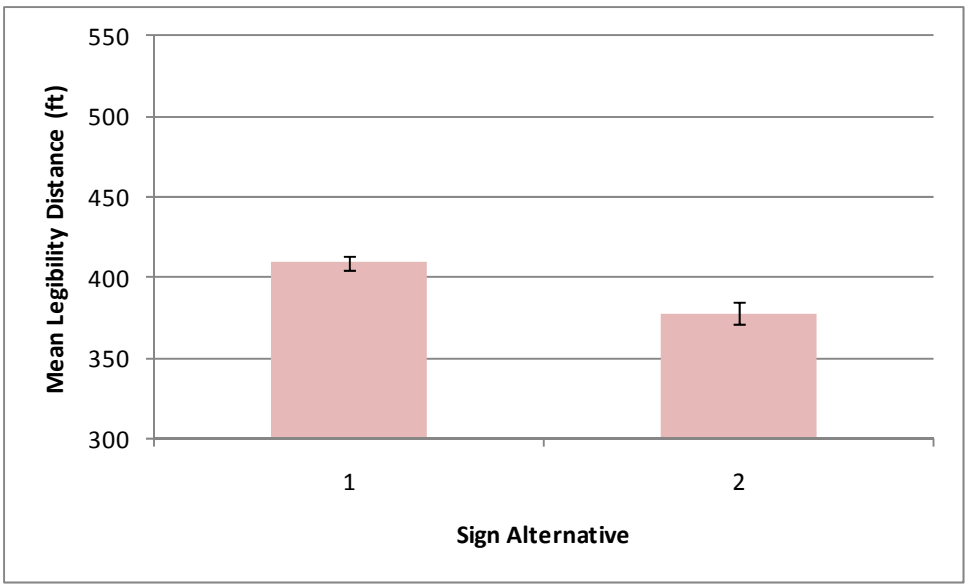


Figure 12: Mean Distances for Uneven Lanes Signs

WINERY

Comprehension

Two signs were evaluated to illustrate that there is a winery at the location of the sign. The comprehension findings are shown in Table 19.

An analysis comparing two proportions showed that Alternative 1 has significantly higher comprehension than Alternative 2, ($Z = 4.86$, $p < .001$).

The multiple choice response that best describes the meaning of these signs is "Winery". 100% of participants chose this response for Alternative 1 and 79.2% chose it for Alternative 2.

The mean rankings show that participants tend to rank Alternative 1 higher than Alternative 2 on how well they illustrate the intended meaning and, on average, think that Alternative 1 would work well and Alternative 2 would not work well.

Table 19: Comprehension Results for Winery Signs

Sign Alternative	Alternative 1	Alternative 2
		
Open-Ended Response		
Understood	97.9%	56.3%
Multiple Choice Response		
Winery	100%	79.2%
Orchard	0	6.3%
Fruit Stand	0	10.4%
Harvest Center	0	4.2%
Ranking		
1 - Would Not Work at All	1%	11%
2	2%	10%
3	2%	19%
4 - Might Work	7%	34%
5	11%	9%
6	21%	7%
7 - Would Work Very Well	55%	8%

Legibility Distance

The mean legibility distance of Alternative 2 was significantly higher than for Alternative 1, $t(94) = 48.96$, $p<.001$. The figure below indicates the mean distance and the 95% confidence interval for each alternative.

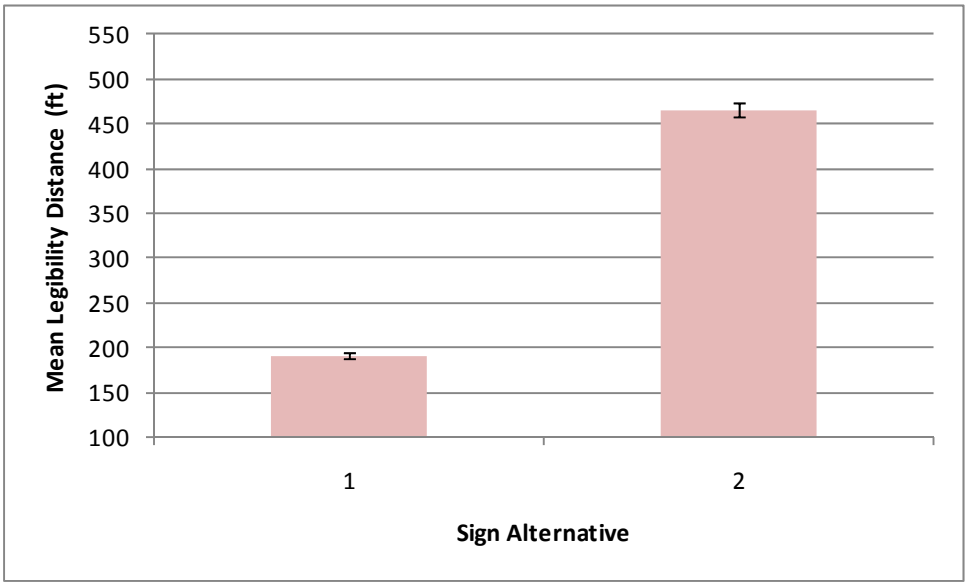


Figure 13: Mean Distances for Winery Signs

FINDINGS AND RECOMMENDATIONS

This section summarizes the findings of this study and explains the recommended alternatives that are effective when taking driver comprehension and legibility requirements into consideration.

COMBINATION HORIZONTAL ALIGNMENT / ADVISORY SPEED

Five yellow-warning symbol-signs, shown in Table 20, were evaluated.

Table 20: Combination Horizontal Alignment / Advisory Speed Signs Evaluated in Study

				
Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative5

Summary of Findings for Combination Horizontal Alignment / Advisory Speed

In the comprehension evaluation, it is apparent that the numeral may not be well understood as an advisory speed (in the case of Alternative 1) and is sometimes confused as the severity of the curve. However, when higher numbers are used, participants were able to determine that the number was giving them appropriate speed information. All signs performed fairly well for legibility distance with Alternative 4 being less due to the level of detail in the symbol design.

Recommendations for Combination Horizontal Alignment / Advisory Speed

The selected alignment signs as tested appear to work well for providing roadway geometry information, but the corresponding numerals may not be appropriate where speeds are less than 15 miles per hour. Research may be needed to determine potential issues with numerals without the traditional abbreviation "M.P.H." However, it is not known if participants understood the difference between an advance warning versus a warning at the start of a horizontal alignment change. Since Alternative 4 resulted in a lower mean legibility distance, the sign should be enlarged in situations where it is used.

CONGESTION AHEAD

The research team evaluated the three symbols shown in Table 21 for this application; all were presented as yellow warning signs.

Table 21: Congestion Ahead Signs Evaluated in Study

		
Alternative 1	Alternative 2	Alternative 3

Summary of Findings for Congestion Ahead

The symbol sign shown in Alternative 3 was not as well comprehended as the text-based alternatives using open-ended responses. Legibility distance was greater for Alternatives 2 and 3 than for Alternative 1, presumably because the shorter letter height required fitting the word "CONGESTION" on the sign.

Recommendations for Congestion Ahead

"BE PREPARED TO STOP" provides information about the appropriate action to take in some cases when there is congestion ahead (in other cases, the congested condition might only require a significant or abrupt reduction in speed, but not a complete stop). Further, the sign has a broad purpose and can be used in other situations (such as vehicle checkpoints, toll plazas, or other locations where drivers need to stop). Therefore, if the intent is to make drivers aware of congestion specifically, the symbol in Alternative 3 may be combined with an educational word message plaque to train drivers of the meaning. Then, the increase in legibility distance that is found in Alternative 3 compared to Alternative 1 will provide further benefit once drivers learn the meaning of the symbol.

DO NOT ENTER

The two signs shown in Table 22 were evaluated for this application. The only difference between Alternatives 1 and 2 is the presence of the DO NOT ENTER legend in Alternative 2, which is similar to the current version in the MUTCD. It should be noted that the MUTCD does not use a black border around the sign, which was an oversight by the research team. Additionally, many international uses of Alternative 1 only use a cutout circle without the white square behind it.

Table 22: Do Not Enter Signs Evaluated in Study

	
Alternative 1	Alternative 2

Summary of Findings for Do Not Enter

Participants do not understand the meaning of the Do Not Enter sign without the text when the sign was presented with an open-ended response. Even with multiple choice responses, some participants thought the meaning was Yield or Stop. The legibility distances were significantly different, but this difference is unlikely to be of practical significance as both signs were legible from over 500 feet (over 150 meters).

Recommendations for Do Not Enter

The existing Do Not Enter sign (Alternative 2) should continue to be used as it is similar to the international version and therefore should be understood by those familiar with the international sign and yet is self-explaining to North American drivers. Additionally, the existing MUTCD standard without a black border should be used since the border on the alternatives tested should not result in any reduced levels of comprehension or legibility.

DO NOT PASS

Table 23 illustrates the alternative Do Not Pass signs that were evaluated. Alternative 2 is currently included in the MUTCD. Alternative 1 represents the symbol used internationally.

Table 23: Do Not Pass Signs Evaluated in Study

	
Alternative 1	Alternative 2

Summary of Findings for Do Not Pass

The open-ended assessment of the comprehension clearly indicated that alternative 2 is the better understood sign. Even when provided with multiple choices, participants interpreted alternative 1 to mean “Caution When Passing”, “No Side to Side Parking”, or “Only One Lane Ahead”. Additionally, Alternative 2 resulted in a higher mean legibility distance.

Recommendations for Do Not Pass

The existing DO NOT PASS sign, Alternative 2, should continue to be used until an improved symbol is developed. It may be possible to introduce an educational plaque to improve comprehension of the sign; however, detailed research should be performed to make sure that people understand the sign before the plaque is removed.

ELECTRIC VEHICLE CHARGING STATION

Table 24 illustrates the four alternatives evaluated in this study. Alternative 1 is currently in the MUTCD.

Table 24: Electric Vehicle Charging Station Signs Evaluated in Study

			
Alternative 1	Alternative 2	Alternative 3	Alternative 4

Summary of Findings for Electric Vehicle Charging Station

Alternative 2 was the best understood symbol. The differences in mean legibility distance were not practically significant; however, Alternative 2 may be improved by widening the plug and separating it from the pump.

Recommendations for Electric Vehicle Charging Station

Based on the results, the researchers recommend using Alternative 2 for electric vehicle charging stations with slight improvements to widen the plug and visually separate the cord from the pump.

FALLEN ROCKS

The research team evaluated three symbols to indicate that there were fallen rocks. Table 25 illustrates these alternatives. All alternatives were presented as warning signs.

Table 25: Fallen Rocks Signs Evaluated in Study

		
Alternative 1	Alternative 2	Alternative 3

Summary of Findings for Fallen Rocks

All three signs were well understood to indicate that a hazard due to fallen rocks. Alternatives 1 and 2 resulted in higher legibility distances than Alternative 3.

Recommendations for Fallen Rocks

Since Alternatives 1 and 2 are both well understood and are both equally legible, the symbolized message of Alternative 1 is preferred because of the increasing proportion of non-English speaking drivers.

FLAGGER AHEAD

Table 26 presents the three alternatives evaluated by the research team. All three alternatives were presented as orange work zone signs. Alternative 2 is the current standard in the MUTCD.

Table 26: Flagger Ahead Signs Evaluated in Study

		
Alternative 1	Alternative 2	Alternative 3

Summary of Findings for Flagger Ahead

The three alternatives received high comprehension ratings; however, when provided options, 22% of the participants thought that Alternative 1 might mean "Crossing Guard Ahead". For legibility distance, Alternative 2 resulted in the highest mean legibility distance.

Recommendations for Flagger Ahead

The current MUTCD standard (Alternative 2) should be retained.

MAXIMUM WIDTH

Table 27 illustrates the two alternatives evaluated in this study.

Table 27: Maximum Width Signs Evaluated in Study

	
Alternative 1	Alternative 2

Summary of Findings for Maximum Width

For the comprehension evaluation, there was no significant difference in comprehension between the two alternatives. The legibility evaluation indicated that Alternative 2 is more legible but the numerals are larger for the sign, so the difference does not have any practical significance. The mean ranking for how the sign works in communicating the message "Maximum Width" was higher for Alternative 2 was higher than Alternative 1.

Recommendations for Maximum Width

Either alternative would be acceptable to indicate maximum width based on the comprehension results; however, since the mean ranking is higher for Alternative 2, Alternative 2 is recommended.

NO LEFT TURN AHEAD

The concept tested for No Left Turn Ahead is shown in Table 28.

Table 28: No Left Turn Ahead Sign Evaluated in Study


Alternative 1

Summary of Findings for No Left Turn Ahead

From the results of the open-ended response question, participants had a difficult time determining the fact that the sign is intended to mean that left turns are restricted **ahead** rather than at the location of the sign. The sign is legible from 410 feet (125 meters) away.

Recommendations for No Left Turn Ahead

Based on the comprehension results, the research team does not recommend that the proposed sign be used without further evaluation or symbol refinement. In the meantime, if a specific message is required, a word legend sign indicating "NO LEFT TURN AT ELM ST" or similar message should be used.

RAILROAD CROSSING ON LEG OF ROUNDABOUT

The research team evaluated a concept to indicate a railroad crossing on the right leg of a roundabout as shown in Table 29.

Table 29: Railroad Crossing on Leg of Roundabout Signs Evaluated in Study


Alternative 1

Summary of Findings for Railroad Crossing on Leg of Roundabout

Participants understood the concept illustrated with a comprehension of 91%. Additionally, the sign was legible from a distance of over 400 feet (over 125 meters).

Recommendations for Railroad Crossing on Leg of Roundabout

Based on the good comprehension levels found in the comprehension evaluation and high mean legibility distance, the researchers recommend that the sign is appropriate for use when communicating the presence of a railroad crossing at a leg of the roundabout. It is important to recognize that the symbol used to depict the roundabout is different from the standard roundabout warning sign, so the impacts will need to be considered by practitioners prior to implementation.

CROSS STREET PREFERENTIAL LANE WARNING SIGNS

The research team evaluated the two concepts shown in Table 30.

Table 30: Cross Street Preferential Lane Warning Signs Signs Evaluated in Study

	
Alternative 1	Alternative 2

Summary of Findings for Cross Street Preferential Lane Warning Signs

Participants generally understood the fact that the right turn had some sort of restriction (bicycle, bus, or HOV); however, only 56% of the participants understood that the restriction was placed for HOV use only.

Recommendations for Cross Street Preferential Lane Warning Signs

Because participants had a general understanding of a restriction, the use of warning signs for preferential lanes at right hand turns may be appropriate. However, since participants do not understand the form of restriction (HOV, bicycle, etc.), another form of guide or regulatory sign showing lane configurations with arrows indicating HOV ONLY and OTHER TRAFFIC may be better alternatives.

ROAD NARROWS

The research team evaluated a symbol sign and a text based sign for Road Narrows. Table 31 illustrates the alternatives evaluated in the study.

Table 31: Road Narrows Signs Evaluated in Study

	
Alternative 1	Alternative 2

Summary of Findings for Road Narrows

Both the open-ended and multiple choice protocols suggest that many drivers will not understand the symbol sign alternative. However, the mean legibility distance was much higher for Alternative 1.

Recommendations for Road Narrows

Based on the poor comprehension of the symbol alternative, the text based sign is more effective in communicating the Road Narrows message and should be retained. A test of a modified version of the symbol that includes lane lines might help to determine whether that improves comprehension of the sign.

LOW SHOULDER WARNING SIGNS

Table 32 illustrates the low shoulder alternatives that were evaluated.

Table 32: Low Shoulder Warning Signs Evaluated in Study

			
Alternative 1	Alternative 2	Alternative 3	Alternative 4

Summary of Findings for Low Shoulder Warning Signs

Participants did not understand the shoulder hazard warning symbols. In many cases, participants thought that there was a change in elevation between two travel lanes and not necessarily between the travel lanes and the shoulder. The text LOW SHOULDER alternative used resulted in similar mean legibility distances to the graphic alternatives whereas SHOULDER DROP OFF uses smaller text and thus was not legible from the same distance. Approximately half of the participants did not believe there was a difference between a low shoulder and a shoulder drop off; however, those who did believe there was a difference also understood the severity of the drop off to be the distinguishing factor.

Recommendations for Low Shoulder Warning Signs

Based on the poor comprehension levels found in the symbol alternatives, the text-based alternatives should be used to provide Low Shoulder Warning information. SHOULDER DROP OFF should be used where the difference in elevation between the travel lanes and shoulder is higher than for LOW SHOULDER.

SURVEY CREW

The research team evaluated a sign to indicate a survey crew as shown in Table 33.

Table 33: Survey Crew Sign Evaluated in Study


Alternative 1

Summary of Findings for Survey Crew

The comprehension test showed that the sign tested was well understood by participants (over 90%). Additionally, the sign was legible from 409 feet (125 meters).

Recommendations for Survey Crew

The researchers recommend the symbol sign to be used when a sign is required to indicate that a survey crew is working near the roadway.

TROLLEY CROSSING

The research team evaluated the trolley crossing signs shown in Table 34.

Table 34: Trolley Crossing Signs Evaluated in Study

	
Alternative 1	Alternative 2

Summary of Findings for Trolley Crossing

Both signs were well understood to indicate that there might be a trolley or light rail crossing. Alternative 2, which includes the "LOOK BOTH WAYS" text and arrow, had a significantly shorter Mean Legibility Distance than alternative 1.

Recommendations for Trolley Crossing

Based on the comprehension and legibility tests, Alternative 1 is recommended for implementation.

UNEVEN LANES

The research team evaluated two alternative signs to indicate Uneven Lanes as depicted in Table 35.

Table 35: Uneven Lanes Signs Evaluated in Study

	
Alternative 1	Alternative 2

Summary of Findings for Uneven Lanes

For the Uneven Lanes sign alternatives, Alternative 2 using a symbol resulted in better comprehension rates than the text. However, Alternative 1 resulted in a legibility distance that was significantly higher.

Recommendations for Uneven Lanes

Because the text "Uneven Lanes" is not well understood without a picture, the research team recommends using Alternative 2 when signing is needed, but should be oversized to improve legibility distance.

WINERY

The research team evaluated the two winery symbols shown in Table 36.

Table 36: Winery Signs Evaluated in Study

	
Alternative 1	Alternative 2

Summary of Findings for Winery

The winery symbol used in Alternative 1 is more complex and resulted in very high comprehension rates; however, because of the complexity, it resulted in significantly lower legibility distances.

Recommendations for Winery

Based on the higher comprehension ratings of Alternative 1, it is recommended that a modified version be developed to increase legibility distance; however, the sign would be appropriate if enlarged or used only on low-speed roads. It may also be possible to improve the legibility of the Alternative 1 symbol by decreasing the complexity somewhat (i.e. using larger and fewer grapes).

OVERALL COMMENTS

In this study, the research team identified several alternative symbols for seventeen traffic signs messages and evaluated the driver comprehension and legibility distance for many of the alternatives. The better performing symbols signs were recommended for adoption in the MUTCD.

Table 37 shows the recommended alternative(s) for each of the symbols/signs evaluated in the study. In some cases, the research team is not recommending any of the symbols evaluated for implementation due to the poor comprehension levels found in the comprehension evaluation.

Table 37: Recommended Sign/Symbol Alternatives

Sign/Symbol	Recommended Alternative(s)
Combination Horizontal Alignment / Advisory Speed	 Consider adding M.P.H. to the sign to indicate advisory speed.
Congestion Ahead	 Use "CONGESTION AHEAD" educational plaque with sign.
Do Not Enter	
Do Not Pass	
Electric Vehicle Charging Station	 Design improvements should be considered by widening the cord and plug while separating the cord away from the pump to increase legibility.
Fallen Rocks	
Flagger Ahead	
Maximum Width	
No Left Turn Ahead	No sign recommended

Sign/Symbol	Recommended Alternative(s)
Railroad Crossing on Leg of Roundabout	
Cross Street Preferential Lane Warning Sign	No sign recommended
Road Narrows	
Low Shoulder Warning Signs	 Sign chosen should be based on elevation difference between the shoulder and travel lanes.
Survey Crew	
Trolley Crossing	
Uneven Lanes	
Winery	 Consider revisions to reduce complexity and increase legibility distance.

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