Traffic Control Devices Pooled Fund Study

Comprehension and Legibility of Selected Symbol Signs
Phase III

Final Report

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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 new signs is particularly important for symbol signs, which rely on a common non-verbal interpretation by a large and diverse population of drivers.

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

The *Manual on Uniform Traffic Control Devices* (MUTCD) is the national standard for traffic control devices.[1] As traffic signs are designed and improved, the Human Factors Team will provide feedback to the MUTCD Team on driver-related characteristics that are observed with the proposed signs.

BACKGROUND

The FHWA produces the MUTCD as a manual which provides standards related to the design and operation of traffic control devices. 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 safe, uniform, and efficient operation of all elements of the traffic stream".[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.

The comprehension, conspicuity, and legibility properties of highway signs are essential in order for the final four requirements to be met. 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 be designed to provide an adequate time for a proper response. Providing adequate time for a proper response is 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 size, shape, and color, composition, lighting or retroreflection, and contrast are combined to draw attention to the devices; that size, shape, color, and simplicity of the 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 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 presented in this report.

By pooling resources and expertise, rather than performing several independent research studies across the country, the TCD PFS provides local and state agencies faster responses to their needs and new technologies using effective assessment skills and tools which enable consistent TCD idea identification and evaluation. The TCD 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 have selected various sign concepts to include as Phase III of a study to evaluate the effectiveness of concepts for new symbol signs. The current document describes this study effort.

LITERATURE REVIEW

There have been various research studies on the effectiveness of traffic signs, including evaluations of comprehension, legibility, and driver response.

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 understandability, legibility distance, 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.[5,6] 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).[5] Katz et al. also had participants speak their interpretations of the road signs aloud while they were transcribed by researchers.[6] Speaking aloud may allow participants to provide more natural and complete responses rather than being constrained by the time it takes to write and possibly leaving out important details. In all 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.[7] Next to this picture, a close-up view of the device was provided along with multiple-choice questions about each sign. In their evaluation of driver comprehension of combined lane-use and destination signing, Golembiewski et al. showed participants images of the signs on basic roadway backgrounds so that each sign assembly was viewed mounted above a 3-lane road.[8] Because the signs provided directional and lane assignment information, backgrounds were necessary in order to provide the basic contextual information required to evaluate comprehension of the sign messages. Each sign was displayed for 3 seconds before participants were asked which lane(s) they could use to get to their target destination.

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.[2] 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*."[2]

Laboratory Evaluations

Desrosiers performed field and laboratory investigations to determine the effectiveness of traffic signs.[9] The author stated that laboratory studies eliminate problems dealing with environmental variables (weather, light, and traffic conditions), 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 be applied to distances obtained in the laboratory.[9]

Zwahlen et al. (1991) suggested several factors that contribute to the underestimation 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.[10]

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.[11], Alicandri and Wochinger[4], and Mahach et al.[12] The Philips et al. study dealt solely with the use of the Sign Simulator (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. Thus it was concluded that signs could be compared against each other for relative recognition; however the actual recognition distances could not be calculated.[11]

The Mahach et al. study hoped to test the significance of the differences in recognition distance between the SignSim Laboratory and the natural environment by using actual scaled signs in TFHRC's Photometric and Visibility Laboratory (PVL).[12] The study pointed out that the effect of the light on signs in a natural environment differs from the SignSim because in the SignSim, the light is diffused as a sign approaches. The study indicated significant differences between the recognition distances obtained in the SignSim and recognition differences obtained in the PVL for nearly all signs which were tested.

Summary

Previous research employs both open-ended and multiple choice responses to obtain information about driver comprehension. Signs have been successfully evaluated both with no background where it is not required and with basic roadway backgrounds where it is necessary that signs be viewed in-context. This study will incorporate similar methods in order to determine if participants understand the general meaning of the signs and to determine whether or not they understand certain specific characteristics of the signs.

The research indicates that TFHRC's SignSim 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 lab results to field results. For comparing alternatives, the SignSim Laboratory is expected to provide the information required.

RESEARCH GOALS

The FHWA Human Factors Team conducted Phase III of the International Symbol Signs study to develop and evaluate proposed alternatives for new traffic signs. The goals of this study were as follows:

- Evaluate driver comprehension of selected signs.
- Measure the legibility distance of selected signs.
- Provide recommendations on signs that merit consideration for addition to the MUTCD.

The TCD PFS panel selected the following sign messages for symbol development and evaluation:

- Alternate Merge
- Bike Symbol
- Grade Crossing (Crossbuck)
- Pedestrian Crossing
- Toll Collection Symbols
- Truck Rollover with Advisory Speed Limit
- Trucks in Roundabouts
- Walk Bikes
- Weave Symbol

RESEARCH APPROACH

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

- Information gathering to see what various state and international agencies are using to convey the target sign messages.
- Identify candidate text and symbol signs based on current practice and through literature review.
- Develop alternatives selected to be researched.
- Perform a laboratory study to evaluate comprehension of the sign alternatives.
- Determine the legibility distance of the sign alternatives.
- Draft recommendations regarding the implementation of the signs that were evaluated.

SIGN CATEGORIES

Examples of various domestic and international symbol signs were gathered and studied prior to the development of symbol sign designs for this study. The following describes each sign category, the intended purpose of the sign, and background information on potential sign alternatives within each category.

Alternate Merge

While there are some variations that have been evaluated or put to use, the MUTCD (2009) does not currently include a symbol sign to indicate "Alternate Merge", which is suggested to be used in a situation where two lanes merge into one, without the right-of-way assigned to either lane.

Two proposed symbol signs were evaluated, as well as text signs in order to determine if a symbol would be effective in conveying this message or if a word legend as the primary sign would better serve this purpose.

Bicycle Symbol

The MUTCD (2009) includes a bicycle symbol (W11-1) which may be used to alert road users to locations where expected entries to the road by bicyclists might occur. Supplemental plaques with legends such as "AHEAD", "NEXT XX MILES" or "SHARE THE ROAD" may be added to provide additional information for notifying road users about the regulations and warnings regarding bicyclists.[1]

The research team evaluated the current bike symbol and various proposed bike symbols to determine what the most effective symbol is for notifying road users about regulations and warnings about bicyclists. The team sought to determine if showing a bike and rider will improve comprehension and legibility.

Grade Crossing (Crossbuck)

The Grade Crossing (R15-1) sign in the MUTCD (2009), commonly referred to as the Crossbuck sign, is used on each approach to every highway-rail grade crossing.[1] The research team evaluated the current MUTCD sign, a Canadian Crossbuck sign, and an alternative that combines the two versions.

Pedestrian Crossing

The MUTCD (2009) states that Yield Here to Pedestrians and Stop Here for Pedestrians (R1-5 series) regulatory signs are placed in advance of a marked crosswalk to indicate the point where drivers must yield or stop for a pedestrian in a crosswalk. A Pedestrian Crossing (W11-2) sign may be used in conjunction with a diagonal downward pointing arrow (W16-7P) plaque and post-mounted at the crosswalk location where an R1-5 series sign is used on the approach.[1] In-Street Pedestrian Crossing (R1-6 series) regulatory signs may also be used to remind drivers of the right-of-way, and are placed at the crosswalk location on the center line, a lane line, or on a median island.[1]

The research team examined each sign alternative as a stand-alone sign, post-mounted and at the crosswalk location in order to address the following questions:

1. Do drivers understand the meaning of the W11-2+W16-7P assembly and what action they are supposed to take?

2. Does a regulatory sign stating a rule of the road significantly enhance driver understanding of what he is supposed to do when a pedestrian occupies the crosswalk?

Toll Collection Symbols

The MUTCD (2009) includes toll collections symbols such as Toll Collector (M4-17), Exact Change (M4-18) or an example Electronic Toll Collection symbol (as shown in M4-20). These symbols are used as guide sign panels that accompany word messages to indicate payment methods allowed at different toll plaza lanes.[1] Various states use similar methods for toll collection signing, however many of the symbols used differ from those in the MUTCD.

An evaluation of the MUTCD symbols, as well as proposed alternatives, is needed to determine if they can be considered for future independent use without word legends. The team evaluated various symbols to indicate toll collection methods (automatic and attended lanes) without the use of text, and also sought to establish standardized symbols that may be employed throughout the country.

Truck Rollover with Advisory Speed Limit

The MUTCD (2009) includes a Truck Rollover Warning (W1-13) sign that may be used to warn drivers of vehicles with a high center of gravity of a turn, curve, or other type of roadway alignment change which might contribute to a loss of control and rollover. This sign is accompanied by an Advisory Speed (W13-1P) plaque.[1] The MUTCD also states that the Hairpin Curve (W1-11) sign may be used to warn drivers when a curve has a change in horizontal alignment of 135 degrees or more.

The research team investigated how drivers interpret the Truck Rollover Warning and Advisory Speed plaque (W1-13 and W13-1P) sign combination. More specifically, do operators of vehicles which are *not* susceptible to load shifts and tip over also interpret the sign and advisory speed as conveying an alignment change and know to react accordingly? In addition, the W1-13 sign uses a generic 135-degree sweep arrow, as opposed to the hairpin arrow. Therefore, the research team will investigate how drivers interpret each arrow type to determine if the 135-degree sweep arrow can be applied generically at tipping hazard locations.

Trucks in Roundabouts

A sign that indicates to drivers that trucks may use multiple lanes in a roundabout is needed, i.e. that trucks may encroach into lanes other than their own as then enter, proceed through and exit the roundabout. There are currently no signs that meet this need in the MUTCD (2009). The research team identified various options for testing that are either in use by some states currently, or that have been proposed for use pending testing of the signs.

Walk Bikes

There is need for a sign that indicates to bicyclists that they are entering an area where they should dismount their bike and walk it through that area. There are currently no signs for this in

the MUTCD (2009). The research team evaluated proposed signs to determine comprehension of such a sign from the perspective of a bicyclist.

Weave Symbol

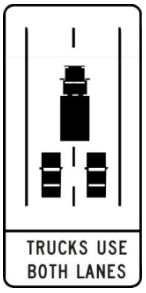
There is currently no symbol sign to accurately warn motorists of a situation where entering and exiting traffic must merge in a short added lane. Therefore, the research team evaluated various proposed symbol signs to depict this message.

SIGN ALTERNATIVES

Table 1 shows the final sign alternatives that were selected for evaluation in each sign category.

Table 1: Sign Alternatives Selected for Evaluation

Sign Category	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
Alternate Merge					
Bike Symbol				None	None
Grade Crossing (Crossbuck)				None	None
Pedestrian Crossing					
Toll Collection Symbols					None

Truck Rollover with Advisory Speed Limit					None
Trucks in Roundabouts					None
Walk Bikes			None	None	None
Weave Symbol (Diverge)					None

METHOD

RESEARCH DESIGN

The research was conducted at the Turner Fairbank Highway Research Center in the Highway Sign Laboratory (Sign Lab). Participants sat approximately 5 feet from a 60" LCD display. Signs were evaluated for comprehension and legibility. The software used for legibility testing is designed to gradually increase the size of the sign, emulating how that sign would appear when driving toward the sign at a specified speed. Sign size, driving speed and start distance were all manipulated to make the representation as accurate as possible. The size of the sign when it becomes legible was then translated into distance. Both the software used 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 driver 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 subjective rankings of the signs. The open-ended and multiple choice sections were between subjects factors, in which participants saw only one sign alternative from each sign category. Participants were shown one sign at a time, and the sign

remained on the screen for as long as they needed to provide their response. Signs were shown on a basic roadway background, in order to provide roadway context for each particular sign category. In the ranking section, participants were shown all sign alternatives for a given category and then ranked each sign on how well each alternative would work to show the intended meaning of the sign. Participants completed all three comprehension sections for a given sign category before moving on to the next category; i.e., they completed open-ended, multiple choice and rankings for the "Alternate Merge" sign category before moving on to the "Bike Symbol" sign category.

Open-Ended

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

They were then asked follow-up questions such as "Would this sign change your behavior?", "What action should you take?" or "Where would you expect to see a sign like this?" The follow up questions varied depending on the type of sign and which questions were most applicable in order to further clarify their understanding or to inquire about a different aspect of the sign.

Multiple Choice

Upon completion of the open-ended questions, participants were asked to choose among three or four definitions (only one of which was correct that *best* described 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 "Form One Lane" text sign option for the open-ended and multiple choice sections, they would now be shown all five sign alternatives in the Alternate Merge sign category, shown in Table 2. Participants were told the intended meaning of the sign, given time to look over all of the sign alternatives, and were asked to rank each alternative on how well it would work to illustrate the intended meaning. Participants ranked the signs on a scale from 1-7, where 1 represented "would not work at all", 4 represented "might work" and 7 represented "would work very well". They were told to rank each sign individually rather than order them; i.e., two signs could have the same ranking, they should not order them from best to worst and vice versa. Participant rankings were not analyzed and did not influence sign recommendations; rankings were used as supplemental subjective information only.

Legibility

The researcher then tested each sign for 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 viewed each sign alternative of all sign categories, totaling 34 test signs. Distracter signs were also included to minimize guesses by participants. The distracter signs included: Stop, Yield, Fire Station, Slower Traffic Keep Right, No U-turn, Deer Crossing,

Intersection, Hospital, Road Work, Airport, and Dead End. All signs were presented in a different random order to each participant, with the exception of "Stop" "Yield" and "No U-Turn" which were always be presented first as practice signs.

For the test, each sign was shown one at a time and on a black background. The sign presentation began at a simulated distance of 1000 feet (304.8 meters). The sign expanded in size to simulate an approach speed of 30 mi/h. Participants were instructed to keep their eyes on the sign, and to press a button on the table in front of them as soon as the sign became legible (i.e. as soon as they could make out the elements of the sign). When the button was pressed, the sign disappeared and the distance was recorded. The participant then described the sign aloud. If the participant was correct, the researcher began a new trial with a different sign. If they were incorrect, the same sign reappeared and continued to increase in size so the participant had another opportunity to press the button when the sign truly became legible.

Correctness was deemed anything that confirmed that the sign was legible to the participant. If the sign size reached the full screen without a correct response, the trial was terminated and the next trial began.

PARTICIPANTS

One hundred and three participants were recruited from the Washington DC metropolitan area, and were obtained through the Human Factors Team research participant database. Participants were at least 18 years of age, possessed a valid U.S. driver's license, and passed a visual acuity test with a minimum of 20/40 binocular vision, corrected if necessary. Prior to the start of the experiment, participants were asked to read and sign the Informed Consent form. Participants were paid $30 for their time.

RESULTS

ALTERNATE MERGE

One hundred and three participants each viewed one of the five Alternate Merge sign alternatives.

Comprehension

The participant answers to the open-ended questions were characterized as providing two responses: (A) Participant understood that two lanes were merging into one; and (B) Participant indicated that drivers should alternate the merge. Results from a Fisher's Exact Test indicated that comprehension levels for Response A varied significantly by sign alternative ($p < 0.0001$). Statistical analysis was not performed for Response B, as some participants may not have provided this information, i.e. Response B simply indicates the participants who provided additional information; there is no way of knowing whether other participants understood this concept and just chose not to specify. Comprehension results are shown in Table 2.

Table 2. Comprehension Results for Alternate Merge Signs

Alternate Merge Sign Alternatives	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
					
Open-Ended Response					
Understood (Response A)	86.96%	68.42%	9.52%	85%	95%
Understood (Response B)	-	10.53%	-	-	-
Multiple Choice Response					
1. Road narrows ahead	30.43%	10.53%	-	10%	20%
2. The median is ending	-	-	-	-	-
3. A lane is ending and will merge into another lane	21.74%	21.05%	28.57%	45%	35%
4. Approaching a median	-	-	-	-	-
5. Two lanes are merging into one, take turns alternating the merge	47.83%	68.42%	71.43%	45%	45%
Ranking					
1 – Would Not Work at All	10.68%	8.74%	9.71%	4.85%	0.97%
2	6.80%	9.71%	6.80%	4.85%	2.91%
3	12.62%	8.74%	12.62%	6.80%	8.74%
4 – Might Work	26.21%	26.21%	30.10%	19.42%	11.65%
5	14.56%	13.59%	15.53%	15.53%	20.39%
6	17.48%	16.50%	11.65%	15.53%	24.27%
7 – Would Work Very Well	11.65%	16.50%	13.59%	33.01%	31.07%

As highlighted in Table 2, the correct multiple choice (MC) option was "Two lanes are merging into one, take turns alternating the merge". While the majority of participants understood that the roadway was going from two lanes down to one lane (as indicated by selecting MC option 3 or 5), only about 45-72% understood that they should take turns alternating the merge. Thus it is not surprising that the highest MC percentages were seen for alternatives 2 and 3, as these are the only signs which provide additional information on merge patterns.

When asked to rank each sign alternative on how well it would work to convey the intended meaning, participants gave alternatives 1, 2, 3, 4 and 5 mean rankings of 4.26, 4.42, 4.24, 5.15 and 5.45, respectively.

Legibility

Sixty two participants viewed each of the Alternate Merge sign alternatives. Results from a Mauchly's sphericity test indicated that the variances of the differences between the legibility distances of the sign alternatives were unequal ($\chi^2(9) = 66.48$, $p < 0.001$) so adjusted univariate statistics (i.e., Huynh-Feldt Epsilon correction factor) were used. A Repeated Measures ANOVA indicated that legibility distances varied significantly by sign alternative, $F(4, 244) = 35.51$, $p <$

0.001. Mean legibility distances for each sign alternative and corresponding 95% confidence limits about the means are displayed in Figure 1. Multiple comparisons were performed using Tukey's Studentized Range test. Sign 1 had the highest mean legibility distance (506.43 ft), which significantly differed from the mean legibility distances of the other four sign alternatives. Sign 2 had the next mean highest legibility distance (462.42 ft), which also differed significant from the mean legibility distances of the other alternatives. Mean legibility distances for Sign 3 (420.11 ft), Sign 4 (407.35 ft), and Sign 5 (436.46 ft) did not differ from each other.

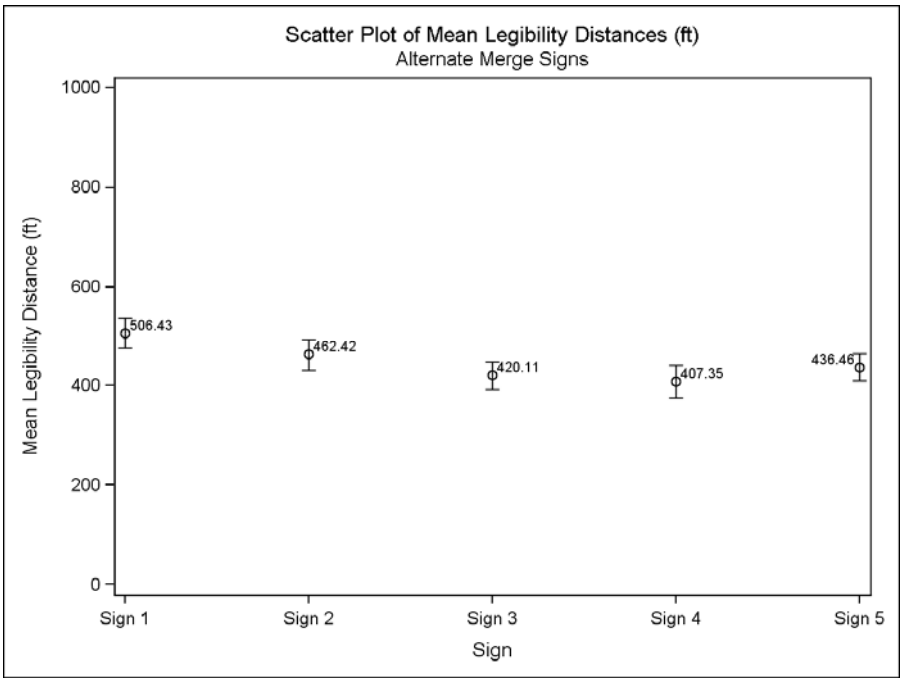


Figure 1. Legibility Results for Alternate Merge Sign Alternatives (95% CL about the mean shown)

BIKE SYMBOL

Sixty on participants each viewed one of the three Bike Symbol sign alternatives.

Comprehension

Participant answers to the open-ended questions were characterized as providing two responses: (A) Participant understood that there was a bike crossing or bike path; and (B) Participant specified that he/she may be sharing the roadway with bikers (i.e. that bikers may not just be crossing the roadway). Results from Fisher's Exact Test indicated that comprehension did not vary significantly by sign alternative for Response A ($p = 0.6557$) or for Response B ($p = 0.3871$). Comprehension results are shown in Table 3.

Table 3. Comprehension Results for Bike Symbol Signs

Bike Symbol Sign Alternatives	Alt 1 	Alt 2 	Alt 3 
Open-Ended Response			
Understood (Response A)	100%	100%	95%
Understood (Response B)	71.43%	65%	85%
Multiple Choice Response			
1. Watch for bicycles riding in the travel lanes	23.81%	45%	20%
2. Watch for bicycles entering or crossing the roadway	76.19%	55%	80%
3. Watch for bicycle parking area	-	-	-
4. Watch for bicycle race in progress	-	-	-
Ranking			
1 – Would Not Work at All	9.84%	3.28%	4.92%
2	9.84%	3.28%	13.11%
3	11.48%	3.28%	8.20%
4 – Might Work	29.51%	18.03%	26.23%
5	8.20%	24.59%	14.75%
6	13.11%	19.67%	14.75%
7 – Would Work Very Well	18.03%	27.87%	18.03%

As highlighted in Table 3, the correct multiple choice response was "Watch for bicycles entering or crossing the roadway". When asked to rank each sign alternative on how well it would work to convey the intended meaning, participants gave alternatives 1, 2 and 3 mean rankings of 4.28, 5.28 and 4.49, respectively.

Legibility

Sixty two participants viewed each of the Bike Symbol sign alternatives. A Repeated Measures ANOVA indicated that legibility distances differed significantly by sign alternative, $F(2,122) = 15.23$, $p < 0.001$. Mean legibility distances for each sign alternative and corresponding 95% confidence limits about the means are displayed in Figure 2. Multiple comparisons were performed using Tukey's Studentized Range test. Sign 1 had the lowest mean legibility distance (499.88 ft), which significantly differed from the mean legibility distances of the other two sign alternatives. Mean legibility distances for Sign 2 (516.16 ft) and Sign 3 (527.81 ft) did not differ from each other.

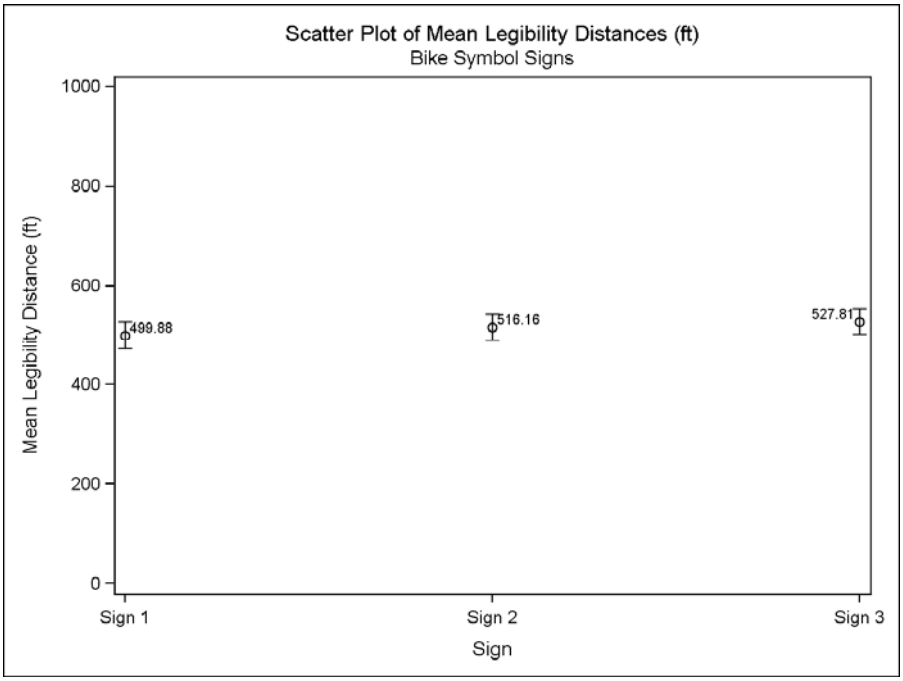


Figure 2. Legibility results for Bike Symbol sign alternatives (95% CL about the mean shown).

GRADE CROSSING (CROSSBUCK)

Sixty three participants each viewed one of the three Crossbuck sign alternatives.

Comprehension

For the open-ended questioning, participants were considered correct if they understood that the sign indicated a railroad crossing/train tracks. Results from Fisher's Exact Test indicated that comprehension did not vary significantly by sign alternative ($p = 0.5289$). All comprehension results are shown in Table 4.

Table 4. Comprehension Results for Crossbuck Signs

Crossbuck Sign Alternatives	Alt 1	Alt 2	Alt 3
			
Open-Ended Response			
Understood	100%	94.74%	95.24%
Multiple Choice Response			
1. Do Not Cross	-	10.53%	-
2. Railroad Crossing	100%	84.21%	100%
3. Do Not Enter	-	5.26%	-
4. No Through Traffic	-	-	-
Ranking			
1 – Would Not Work at All	-	53.97%	-
2	1.59%	9.52%	-
3	4.76%	6.35%	-
4 – Might Work	12.70%	15.87%	4.76%
5	3.17%	1.59%	6.35%
6	22.22%	9.52%	19.05%
7 – Would Work Very Well	55.56%	3.17%	69.84%

The only incorrect responses for the multiple choice question were for alternative 2. Additionally, when asked to rank each sign alternative on how well it would work to convey the intended meaning, alternative 2 (M = 2.43) had a lower mean ranking than alternative 1 (M = 6.06) and alternative 3 (6.54).

Legibility

Sixty two participants viewed each of the Crossbuck sign alternatives. A Repeated Measures ANOVA indicated that legibility distances did not differ significantly by sign alternative. The overall mean legibility distance for the Crossbuck sign alternatives was 626.21 ft.

PEDESTRIAN CROSSING

One hundred and three participants each viewed one of the five Pedestrian Crossing sign alternatives.

Comprehension

Participant answers to the open-ended questions were characterized as providing two responses: (A) Participant generally understood to watch for pedestrians crossing; and (B) Participant specified to watch for pedestrians crossing in a crosswalk (i.e., the sign was indicating a crosswalk). Results from Fisher's Exact Test indicated that comprehension did not vary significantly by sign alternative for Response A ($p \approx 1.000$) or for Response B ($p = 0.0972$). Comprehension results are shown in Table 5.

Table 5. Comprehension Results for Pedestrian Crossing Signs

Pedestrian Crossing Sign Alternatives	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
					
Open-Ended Response					
Understood (Response A)	100%	100%	100%	100%	100%
Understood (Response B)	100%	78.95%	76.19%	85%	90%
Multiple Choice Response					
1. Yield until the pedestrian has cleared the crosswalk	43.48%	42.11%	19.05%	5%	55%
2. Yield until you can proceed without hitting the pedestrian	8.70%	21.05%	-	-	5%
3. Come to a complete stop until the pedestrian has cleared the crosswalk	47.83%	26.32%	61.90%	80%	35%
4. Come to a complete stop until you can proceed without hitting the pedestrian	-	10.53%	19.05%	15%	5%
Ranking					
1 – Would Not Work at All	1.94%	9.71%	-	-	-
2	6.8%	9.71%	-	-	0.97%
3	8.74%	10.68%	-	-	-
4 – Might Work	27.18%	21.36%	-	-	5.83%
5	15.53%	18.45%	-	-	9.71%
6	16.5%	14.56%	-	-	15.53%
7 – Would Work Very Well	23.3%	15.53%	-	-	67.96%

For the multiple choice response, participants were asked to select the choice which best represented the solution to the following situation: "If there is a pedestrian in the crosswalk, you should do what?" There was no correct choice since the correct response depended on the sign alternative shown to the participant.

When asked to rank sign alternatives 1, 2 and 5 on how well they would work to convey "Pedestrian Crossing", participants gave mean rankings of 4.90, 4.35 and 6.43, respectively. Participants were not asked to rank alternatives 3 or 4 because they were the same as 2 and 5 but with "stop" instead of "yield".

Legibility

Sixty two participants viewed each of the Pedestrian Crossing sign alternatives. Results from a Mauchly's sphericity test indicated that the variances of the differences between the legibility distances of the sign alternatives were not equal ((9) = 19.57, p = 0.021) so adjusted univariate

statistics were used. A Repeated Measures ANOVA indicated that legibility distances differed significantly by sign alternative, $F(4,244) = 34.70$, $p < 0.001$. Mean legibility distances for each sign alternative and corresponding 95% confidence limits about the means are displayed in Figure 3. Multiple comparisons were performed using Tukey's Studentized Range test. Sign 1 had the highest mean legibility distance (505.12 ft), which significantly differed from the mean legibility distances of the other sign alternatives. The mean legibility distance for Sign 2 (445.91 ft) was significantly higher than the mean legibility distance for Sign 4 (409.91 ft) and Sign 5 (418.77 ft). The mean legibility distance for Sign 3 (428.83 ft) did not differ from the mean legibility distance for Sign 4 or Sign 5.

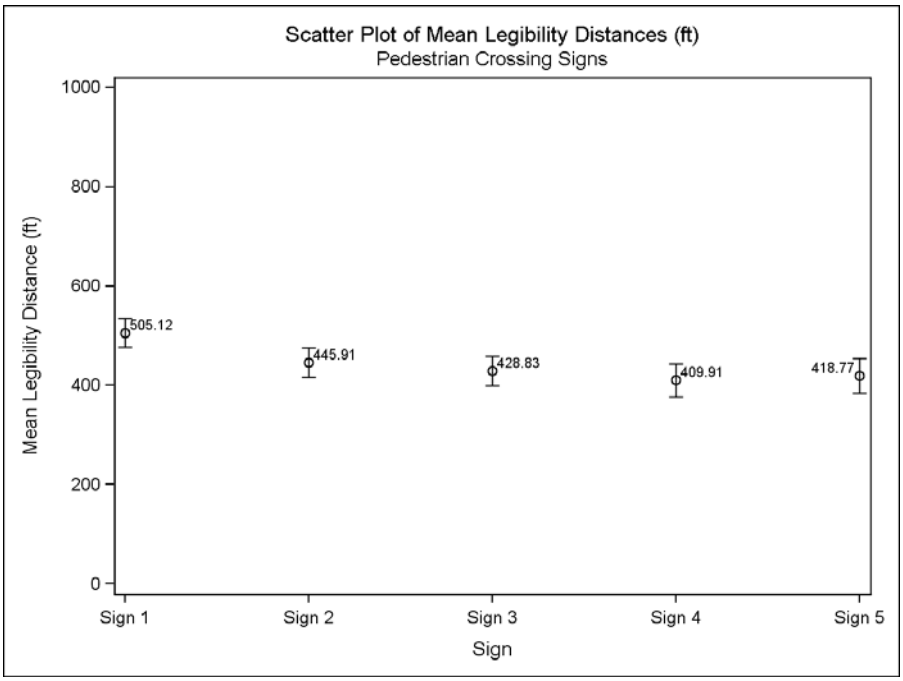


Figure 3. Legibility Results for Pedestrian Crossing Sign Alternatives (95% CL About the Mean Shown).

TOLL COLLECTION SYMBOLS

For the Toll Collection symbols, the exact change symbols and the attendant symbols were analyzed separately, as they convey two different meanings. Forty three participants each saw one of the two exact change symbols, and forty participants each saw one of the two attendant symbols.

Comprehension

First, participants were asked open-ended questions about either an exact change symbol, or an attendant symbol. They were shown an image of their symbol above one lane of a three-lane toll plaza. There were no signs above the other two lanes. Participant answers to the open-ended questions were characterized as providing two responses: (A) Participant generally understood that the sign indicated a toll where they needed to pay money; and (B) Participant specified that they needed exact change (if they viewed the exact change symbol) or that there was an attendant in the booth (if they viewed the attendant symbol). Results from Fisher's Exact Test for the exact change symbols indicated that comprehension did not vary significantly by sign alternative for

Question A (p = 1.000) or for Question B (p = 1.000). Results from a Fisher's Exact Test for the attendant symbols indicated that comprehension did not vary significantly by sign alternative for Question A (p = 1.000), but there were significant differences in comprehension for Question B (p < 0.005). Comprehension results are shown in Table 6.

Table 6. Comprehension Results for Toll Collection Symbols

Exact Change Symbol Alternatives	**Alt C1** 	**Alt C2** 
Open-Ended Response		
Understood (Response A)	91.3%	95%
Understood (Response B)	57.14%	57.89%
Attendant Symbol Alternatives	**Alt A1** 	**Alt A2** 
Open-Ended Response		
Understood (Response A)	100%	100%
Understood (Response B)	38.1%	84.21%

After the open-ended comprehension, participants were shown the same image of a three-lane toll plaza, with the original symbol they viewed, as well as another symbol of the opposite category, and a "Tollpass" sign. Therefore, there were four different conditions, in which each exact change symbol was shown with each attendant symbol; participants saw one of the four combinations: C1A1, C1A2, C2A2 or C2A2. Participants viewed the same image and sign combination four different times. With each view, they were given one of the following scenarios and asked to indicate all possible lanes that they could use:

Scenario A: The toll is .50 cents. You have no cash and you have a toll pass.
Scenario B: The toll is .50 cents. You have a 5 dollar bill.
Scenario C: The toll is .50 cents. You have a 5 dollar bill and 3 quarters.
Scenario D: The toll is .50 cents. You have 3 quarters and need a receipt.

The presentation of scenarios was randomized. Each sign condition and respective comprehension results of all scenarios (A-D) are shown in Table 7. The correct lanes (i.e. all possible lanes that could be used for a particular scenario) are highlighted in yellow. The table indicates the percentage of participants who selected each lane, as well as the percentage of total correctness for each condition; participants were considered correct if they selected exactly the lanes which could be used for that scenario, and no lanes which could not be used.

Table 7. Percent Correct for Toll Collection Scenarios A-D and Lane Selections for each Scenario

C1A1			C2A1		
					
Lane 1	**Lane 2**	**Lane 3**	**Lane 1**	**Lane 2**	**Lane 3**
Scenario A (87%)			**Scenario A (86%)**		
4%	13%	100%	5%	14%	100%
Scenario B (91%)			**Scenario B (100%)**		
9%	100%	4%	-	100%	-
Scenario C (78%)			**Scenario C (62%)**		
100%	78%	-	95%	67%	-
Scenario D (100%)			**Scenario D (90%)**		
-	100%	-	10%	90%	-
C1A2			**C2A2**		
					
Lane 1	**Lane 2**	**Lane 3**	**Lane 1**	**Lane 2**	**Lane 3**
Scenario A (89%)			**Scenario A (90%)**		
5%	11%	100%	5%	5%	100%
Scenario B (100%)			**Scenario B (100%)**		
-	100%	-	-	100%	-
Scenario C (89%)			**Scenario C (70%)**		
100%	89%	-	100%	70%	-
Scenario D (89%)			**Scenario D (100%)**		
11%	100%	5%	-	100%	-

When averaging the correct percentages across all four scenarios, the mean correctness was 89%, 91.75%, 84.5% and 90% for the sign combinations of C1A1, C1A2, C2A1 and C2A2, respectively.

Legibility

Sixty two participants viewed each of the Truck Roll sign alternatives. A Repeated Measures ANOVA indicated that legibility distances differed significantly by sign alternative ($F(3,183) = 9.42$, $p < 0.001$). Mean legibility distances for each sign alternative and corresponding 95% confidence limits about the means are displayed in Figure 4. Multiple comparisons were performed using Tukey's Studentized Range test. Mean legibility distances for Sign C1 (505.00 ft) and Sign A1 (501.32 ft) differed significantly from the mean legibility distances for Sign A2 (445.45 ft) and Sign C2 (460.26 ft).

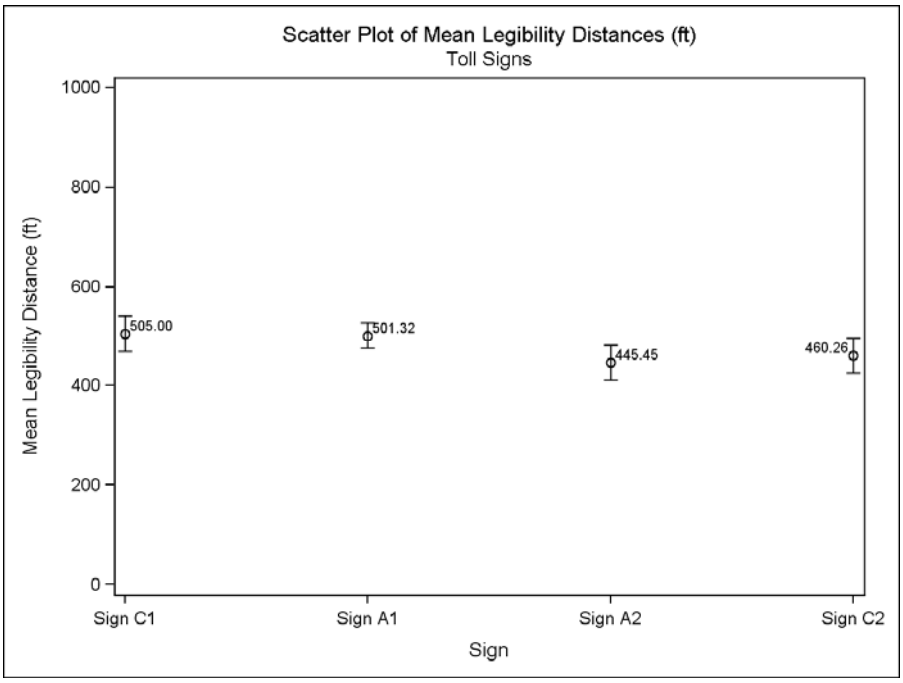


Figure 4. Legibility Results for Toll Collection Symbol Sign Alternatives (95% CL About the Mean Shown).

TRUCK ROLLOVER WITH ADVISORY SPEED LIMIT

Eighty two participants each viewed one of the four Truck Rollover with Advisory Speed sign alternatives.

Comprehension

Participants were considered correct if they understood that there was an alignment change at the exit ramp ahead and that the advisory speed was 35 MPH. These percentages are shown as Response A in Table 8 below. Results from Fisher's Exact Test indicated that comprehension did not vary significantly by sign alternative, $p = 0.053$.

Response B represent the percentage of participants who understood the sign (Response A), and further specified that the speed advisory applies to all drivers (as opposed to trucks only).

Response C represents the percentage of participants who understood the sign (Response A), and further specified that the sign indicated a risk of tipping.

Response D represents the percentage of participants who indicating a risk of tipping (Response B), and further specified that the risk of tipping applies to all drivers (as opposed to trucks only).

Table 8. Comprehension Results for Truck Rollover with Advisory Speed Limit Signs

Truck Rollover with Advisory Speed Limit Sign Alternatives	**Alt 1** 	**Alt 2** 	**Alt 3** 	**Alt 4** 
Open-Ended Response				
Understood (Response A)	82.61%	100%	95%	100%
(Response B – speed advisory applies to all, not just trucks)	65%	100%	78.95%	100%
(Response C – risk of tipping)	85%	10.53%	73.68%	0.05%
(Response D – risk of tipping applies to all, not just trucks)	29.41%	100%	28.57%	-
Multiple Choice Response				
1. Slow down when entering tunnel	-	-	-	-
2. Wrong way, turn around	-	-	-	-
3. There is a sharp curve at the exit ramp ahead, the advisory speed is 35 MPH	95.65%	100%	90%	100%
4. Watch for tipping trucks	4.35%	-	10%	-
Ranking				
1 – Would Not Work at All	2.44%	18.29%	2.44%	13.41%
2	1.22%	9.76%	1.22%	10.98%
3	2.44%	9.76%	4.88%	12.20%
4 – Might Work	8.54%	17.07%	9.76%	25.61%
5	14.63%	17.07%	15.85%	19.51%
6	28.05%	9.76%	30.49%	7.32%
7 – Would Work Very Well	42.68%	18.29%	35.37%	10.98%

When asked to rank sign alternatives 1, 2, 3 and 4 on how well they would work to convey the intended meaning, participants gave mean rankings of 5.87, 4.07, 5.68 and 3.93, respectively.

Legibility

Sixty two participants viewed each of the Truck Rollover with Advisory Speed sign alternatives. A Repeated Measures ANOVA indicated that legibility distances did not differ significantly by sign alternative. The overall mean legibility distance for all sign alternatives was 438.69 ft.

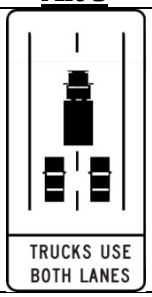
TRUCK ROUNDABOUT SIGNS

Eighty four participants each viewed one of the four Pedestrian Crossing sign alternatives.

Comprehension

Participants were considered correct if they reported the possibility of trucks crossing into or driving in multiple lanes (e.g. they were not correct if they stated simply to be cautious of trucks or to watch for trucks due to blind spots). Results from Fisher's Exact Test indicated that comprehension varied significantly by sign alternative ($p < 0.05$). Comprehension results are shown in Table 9.

Table 9. Comprehension Results for Truck Roundabout Signs

Truck Roundabout Sign Alternatives	Alt 1	Alt 2	Alt 3	Alt 4
				
Open-Ended Response				
Understood	65.22%	33.33%	70%	25%
Multiple Choice Response				
1. Trucks may encroach in both lanes through roundabout	78.26%	42.86%	80%	65%
2. Trucks should use both lanes through roundabout	4.35%	-	20%	30%
3. Trucks in the left lane may encroach in the right lane through the roundabout	8.70%	9.52%	-	-
4. Trucks in the right lane may encroach in the left lane through the roundabout	8.70%	47.62%	-	5%
Ranking				
1 – Would Not Work at All	5.95%	8.33%	11.9%	14.29%
2	-	15.48%	8.33%	11.9%
3	4.76%	11.9%	11.9%	7.14%
4 – Might Work	21.43%	22.62%	15.48%	16.67%
5	25%	13.1%	14.29%	11.9%
6	21.43%	13.1%	16.67%	15.48%
7 – Would Work Very Well	21.43%	15.48%	21.43%	22.62%

When asked to rank sign alternatives 1, 2, 3 and 4 on how well they would work to convey the intended meaning, participants gave mean rankings of 5.10, 4.18, 4.48 and 4.37, respectively.

Legibility

Sixty two participants viewed each of the Truck Roundabout sign alternatives. Results from a Mauchly's sphericity test indicated that the variances of the differences between the legibility distances of the sign alternatives were not equal ($\chi^2(5) = 37.33$, $p < 0.001$) so adjusted univariate statistics were used. A Repeated Measures ANOVA indicated that legibility distances differed significantly by sign alternative, $F(3,183) = 108.28$, $p < 0.001$. Mean legibility distances for each sign alternative and corresponding 95% confidence limits about the means are displayed in Figure 5. Multiple comparisons were performed using Tukey's Studentized Range test. Sign 4

had the highest mean legibility distance (504.72 ft), which was significantly different from the mean legibility distance for Sign 1 (367.18 ft), Sign 2 (362.52 ft), and Sign 3 (345.40 ft).

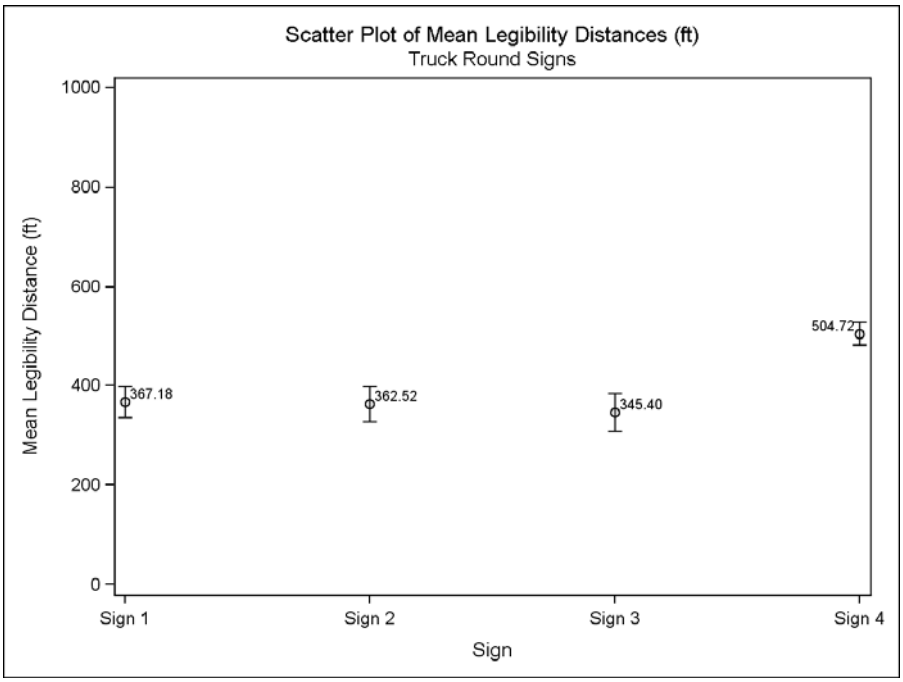


Figure 5. Legibility Results for Truck Roundabout Sign Alternatives (95% CL About the Mean Shown).

WALK BIKES

Eighty three participants each viewed one of the two Walk Bikes sign alternatives.

Comprehension

Participants were considered correct if they understood that the sign indicated they should dismount their bike and walk it through the area. A Fisher's Exact Test indicated that there was a significant difference in comprehension between the two sign alternatives ($p < 0.05$). Comprehension results are shown in Table 10.

Table 10. Comprehension Results for Walk Bikes Signs

Walk Bikes Sign Alternatives	Alt 1 	Alt 2 
Open-Ended Response		
Understood	88.64%	61.54%
Multiple Choice Response		
Do not ride your bicycle without a helmet	-	-
Bicycle parking area	-	-
No bikes allowed past this point	-	-
Dismount your bicycle and walk it through this area	100%	100%
Ranking		
1 – Would Not Work at All	-	6.10%
2	1.22%	4.88%
3	-	2.44%
4 – Might Work	2.44%	31.71%
5	2.44%	15.85%
6	19.51%	18.29%
7 – Would Work Very Well	73.71%	19.51%

All participants were correct for the multiple choice question. When asked to rank the signs on how well they would work to show the intended meaning, participants gave a mean ranking of 7.74 for alternative 1 and 5.96 for alternative 2.

Legibility

Legibility distances were not examined for the Walk Bikes sign alternatives since these signs were viewed from the perspective of a bicyclist.

WEAVE

Eighty three participants each viewed one of the four Weave sign alternatives.

Comprehension

For the open-ended responses, participants were considered correct if they understood that merging traffic (entering the roadway) and diverging traffic (exiting the roadway) were going to cross paths. A Fisher's Exact Test indicated that comprehension did not vary significantly by sign alternative ($p = 0.1382$). Comprehension results are shown in Table 11.

Table 11. Comprehension Results for Weave Signs

Weave Sign Alternatives	Alt 1	Alt 2	Alt 3	Alt 4
				
Open-Ended Response				
Understood	60.87%	78.95%	42.86%	65%
Multiple Choice Response				
1. Traffic entering and exiting the highway must merge in a short added lane	52.17%	94.74%	57.14%	65%
2. Highway splits ahead and will go in two different directions	47.83%	5.26%	42.86%	35%
3. You will approach a roundabout when you exit	-	-	-	-
4. New traffic pattern ahead due to construction	-	-	-	-
Ranking				
1 – Would Not Work at All	45.12%	19.51%	34.15%	31.71%
2	12.2%	10.98%	15.85%	19.51%
3	4.88%	8.54%	15.85%	10.98%
4 – Might Work	24.39%	30.49%	14.63%	18.29%
5	6.1%	10.98%	9.76%	13.41%
6	7.32%	14.63%	7.32%	4.88%
7 – Would Work Very Well	-	4.88%	2.44%	1.22%

For the multiple choice question, participants performed the best on alternative 2, with nearly 100% correctness. When asked to rank each sign on how well it would work to show the intended meaning, participants gave alternatives 1, 2, 3 and 4 mean rankings of 2.56, 3.66, 2.82 and 2.82, respectively.

Legibility

Sixty two participants viewed each of the Weave sign alternatives. Results from a Mauchly's sphericity test indicated that the variances of the differences between the legibility distances of the sign alternatives were not equal ($\chi^2(5) = 17.25$, $p = 0.004$) so adjusted univariate statistics were used. A Repeated Measures ANOVA indicated that legibility distances differed significantly by sign alternative ($F(3,183) = 16.11$, $p < 0.001$). Mean legibility distances for each sign alternative and corresponding 95% confidence limits about the means are displayed in Figure 6. Multiple comparisons were performed using Tukey's Studentized Range test. Sign 1 had the highest mean legibility distance (506.73 ft), which was significantly different from the mean legibility distance for Sign 2 (440.67 ft) and Sign 4 (473.71 ft). The mean legibility distance for Sign 3 (490.80 ft) and Sign 4 differed significantly from the mean legibility distance for Sign 2.

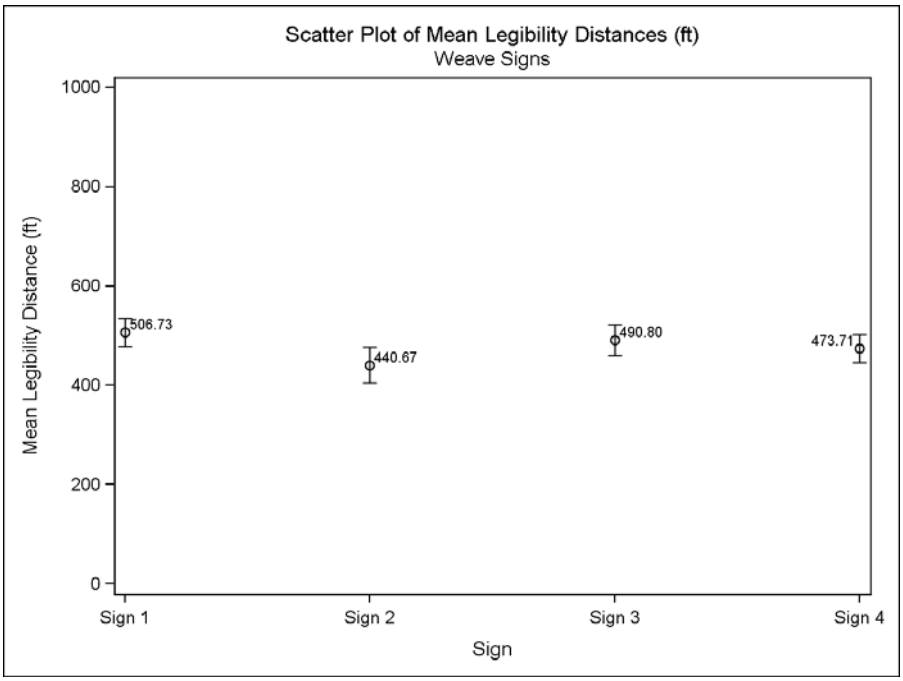


Figure 6. Legibility results for Weave sign alternatives (95% CL about the mean shown).

DISCUSSION AND CONCLUSIONS

ALTERNATE MERGE

Five alternatives were evaluated for an Alternate Merge sign, shown in Table 12.

Table 12. Alternate Merge Signs Evaluated in Study

Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
				

Summary Findings for Alternate Merge

The results indicated that participants best understood that two lanes were merging into one lane for alternative 5 (95%), alternative 1 (86.96%) and alternative 4 (85%). It's not surprising that alternative 5 conveyed this message the best, as it is the only sign which indicates specifically that there will only be one lane ahead. It is also not surprising that alternative 1 performed well, as it symbolically shows that two lanes are coming together as one, rather than one lane ending and merging into the other. Participants only specified that they should take turns alternating the merge for alternative 2, with approximately 11% of participants who understood this part of the message. The symbolic display of two lines combining evenly to one arrow may have helped to display this message. It is also possible that participants simply did not report specific merge patterns either because (A) drivers are typically more familiar with situations where one lane is

ending and merging into another, rather than two lanes merging evenly into on or (B) drivers who assume that a merge implies alternating as it is, may not have felt the need to further specify. Poor comprehension for alternative 3 may be due to the ambiguity of the word "alternate" used on the sign. For example, if drivers read the word as a verb, they may be more likely to interpret the sign as meaning they should take alternating turns merging; however if drivers read the word as a noun, they may be more likely to interpret the sign as meaning there is a different merge pattern that usual (e.g. there is temporary construction and therefore there is a new merge pattern ahead).

Legibility distances were the best for the two symbol signs, alternative 1 (506.43ft) and alternative 2 (462.42). For the text-based signs, alternative 5 (436.46ft) performed the best.

Recommendations for Alternate Merge

The intent of an Alternate Merge sign is to indicate to drivers that two lanes are merging into one, without the right-of-way assigned to either lane. Thus it is important that the sign effectively convey to drivers that they should take turns alternating the merge. Alternatives 1 and 5 performed the best for indicating that two lanes were merging into one. However it was not apparent that the signs sufficiently conveyed to drivers that there was no right-of-way and they should alternate the merge. Therefore, no signs are recommended for use. It may however be useful to test alternatives 1 and 5 with the addition of a plaque indicating instructions for the merge pattern, e.g. a plaque reading "take turns".

BIKE SYMBOL

Three alternatives were evaluated for a Bike Symbol sign, shown in Table 13.

Table 13. Bike Symbol Signs Evaluated in Study

Alternative 1	Alternative 2	Alternative 3
		

Summary Findings for Bike Symbol

The results showed that alternative 1 (100%), alternative 2 (100%) and alternative 3 (95%) are all highly effective in conveying that there is a bike path/bike crossing. However, participants were slightly less likely to interpret the sign as indicating that bicyclist may be sharing the roadway as well (i.e., not just crossing the roadway), though the differences in alternative 1 (71.43%), alternative 2 (65%) and alternative 3 (85%) were significant. Additionally, when considering the multiple choice responses, only 55% selected the proper meaning for alternative 2, which is much lower than alternative 1 (76.19%) and alternative 3 (80%). The legibility testing indicated that alternative 3 (527.81ft) had a higher legibility distance than alternative 2 (516.16ft) and alternative 1(499.88ft).

Recommendations for Bike Symbol

Based on the results of comprehension and legibility testing, it is recommended that the use of the current MUTCD standard, alternative 1, continue to be used. The other alternatives did not offer significant enough improvements to comprehension and legibility to justify changing the standard.

GRADE CROSSING (CROSSBUCK)

Three alternatives were evaluated for a Crossbuck sign, shown in Table 14.

Table 14. Crossbuck Signs Evaluated in Study

Alternative 1	Alternative 2	Alternative 3
		

Summary Findings for Crossbuck

All three alternatives were comprehended well, with 100% comprehension for alternative 1, 94.74% for alternative 2, and 95.24% for alternative 3. Legibility testing indicated that alternative 3 had worse legibility (614.86ft) than alternative 1 (626.99ft) and alternative 2 (636.77ft). Participants only made incorrect selections on the multiple choice section for alternative 2, mistaking it as meaning "Do Not Cross" or "Do Not Enter". Additionally, the subjective rankings were much lower for alternative 2 (M = 2.43) than they were for alternative 1 (M = 6.06) and alternative 3 (6.54).

The signs were shown on a background with railroad tracks in view, as would most likely be the case in the real world. However, alternative 2 may have performed worse on the multiple choice and ranking responses because without having railroad tracks in direct view, it may be easier to mistake alternative 2 as meaning something different.

Recommendations for Crossbuck

Based on the results of comprehension and legibility testing, it is recommended that alternative 1 continue to be used. Adding the red border (alternative 3) seems to decrease legibility of the sign, and further testing may be required to verify that alternative 2 would be understood in a real-world setting.

PEDESTRIAN CROSSING

Three alternatives were evaluated for a Pedestrian Crossing sign, shown in Table 15.

Table 15. Pedestrian Crossing Signs Evaluated in Study

Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
				

Summary Findings for Pedestrian Crossing

Comprehension for all five sign alternatives was 100% based on the understanding that drivers should look for pedestrians crossing. When considering participants who specifically understood to look for pedestrians crossing in a crosswalk (i.e. that the sign was indicating a crosswalk; rather than a general crossing area such as a school zone where there are typically pedestrians around), the comprehension dropped a bit. Alternative 1 still had 100% comprehension, whereas alternatives 2, 3, 4 and 5 dropped to approximately 79%, 76%, 85% and 90% comprehension, respectively (though they were not significantly different). When asked what they should do when there is a pedestrian in the crosswalk, approximately 91% (alt1), 68% (alt2), 81% (alt3), 85% (alt4) and 90% (alt5) of participants indicated they should yield or stop until the pedestrian as cleared the crosswalk (rather than stop/yield until they can proceed without hitting the pedestrian). Alternative 1 had the best legibility distance (505.12ft), followed by alternative 2 (445.91ft), alternative 3 (428.83ft), alternative 5 (418.77ft) and alternative 4 (409.91ft).

Recommendations for Pedestrian Crossing

Alternative 1 had the highest overall comprehension, as well as the highest legibility distance. Alternatives 2-5 also performed well; however it is not recommended that alternatives 2-5 be used in place of the current standard (alternative 1) at the location of the crosswalk as they did not improve driver comprehension. Therefore, it is recommended that alternative 1, the W11-2+W16-7P assembly, continue to be used post-mounted at the crosswalk location where an R1-5 series sign is used on the approach.

TOLL COLLECTION SYMBOLS

Four alternatives were evaluated for Toll Collection signs, shown in Table 16.

Table 16. Toll Collection Signs Evaluated in Study

Alternative C1	Alternative C2	Alternative A1	Alternative A2
			

Summary Findings for Toll Collection

Comprehension of the exact change symbols did not vary significantly. Additionally, when looking at the four different toll plaza scenarios (see Table 7), the conditions with alternative C1 had overall correctness of approximately 89% (C1A1) and 92% (C1A2), and the conditions with alternative C2 had overall correctness of approximately 85% (C2A1) and 90% (C2A2), averaging 90.5% correctness for all C1 conditions and 87.5% correctness for all C2 conditions. Alternative C1 (505ft) had higher legibility distances than alternative C2 (160.26ft).

Comprehension of the attendant symbols did not vary significantly when considering driver understanding of a toll to be paid (both with 100%), however alternative A2 had significantly higher comprehension (84.21%) than alternative A1 (38.1%) when considering those who specified that there was an attendant in the toll booth. It should be noted however that participants may have understood that an attendant was present, but simply did not specify this in their response. When looking at the four different toll plaza scenarios (see Table 7), the conditions with alternative A1 had overall correctness of approximately 89% (C1A1) and 85% (C2A1) and the conditions with alternative A2 had overall correctness of approximately 92% (C1A2), and 90% (C2A2), averaging 87% correctness for all A1 conditions and 91% correctness for all A2 conditions. Alternative A1 (501.32ft) had higher legibility distances than alternative A2 (445.45ft).

Recommendations for Toll Collection

It is recommended that alternatives C1 and A1 continue to be used.

TRUCK ROLLOVER WITH ADVISORY SPEED LIMIT

Four alternatives were evaluated for Truck Rollover signs, shown in Table 17.

Table 17. Truck Rollover with Advisory Speed Signs Evaluated in Study

Alternative 1	Alternative 2	Alternative 3	Alternative 4
			

Summary Findings for Truck Rollover with Advisory Speed

All alternatives performed well in the open-ended comprehension, with 83%, 100%, 95% and 100% comprehension for Alternatives 1, 2, 3 and 4, respectively. Participants are more likely to interpret a risk of tipping when viewing alternatives 1 (85%) and 3 (74%) than when viewing alternatives 2 (11%) and 4 (.05%). There were no significant differences in legibility distance between the four alternatives.

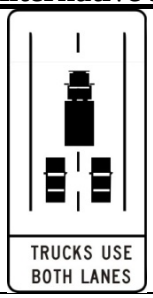
Recommendations for Truck Rollover with Advisory Speed

There were no statistically significant differences in sign alternatives, therefore the current sign, alternative 1, is recommended for continued use. Additionally, alternative 1 resulted in the highest percentages of perceived risk of tipping; it is expected that a perceived risk of tipping could make motorists more likely to adhere to the advisory speed.

TRUCK ROUNDABOUT SIGNS

Four alternatives were evaluated for Truck Roundabout signs, shown in Table 18.

Table 18. Truck Roundabout Signs Evaluated in Study

Alternative 1	Alternative 2	Alternative 3	Alternative 4
			

Summary Findings for Truck Roundabout

Alternatives 1 and 3 had the highest comprehension, with 65% and 70%, respectively. Alternatives 2 and 4 had low comprehension (33% and 25% respectively) indicating they are not suitable recommendations. On the multiple choice question, there were 78%, 43%, 80% and 65% correct responses for alternatives 1, 2, 3 and 4, respectively. Participants ranked alternative 1 the highest (5.10), followed by alternative 2(4.48), alternative 3(4.37) and alternative 1(4.18). There were significant differences in legibility distances by alternative, though alternatives 1, 2 and 3 all had similar distances which were within an acceptable range.

Recommendations for Truck Roundabout

Alternative 1 is recommended for use as comprehension and legibility distance were both within an acceptable range. Alternative 1 is recommended over alternative 3 (which also performed well) due to the fact that alternative 1 can be used in a variety of locations (e.g. turns or routes that are frequented by logging trucks or other large trucks), whereas alternative 3 would be limited to two-land roundabouts. Additionally, it is possible that alternative 3 could be interpreted as a regulatory sign indicating to trucks that they may use both lanes, rather than a warning sign indicating to all motorists that trucks may encroach in multiple lanes.

WALK BIKES

Two alternatives were evaluated for Walk Bikes signs, shown in Table 19.

Table 19. Walk Bikes Signs Evaluated in Study

Alternative 1	Alternative 2
	

Summary Findings for Walk Bikes

Comprehension was significantly higher for alternative 1 (89%) than for alternative 2 (62%), though all participants responded correctly to the multiple choice question. Participant rankings indicated a preference with alternative 1 (7.74) over alternative 2 (5.96).

Recommendations for Walk Bikes

The comprehension results indicate that bicyclists may misinterpret the meaning of the sign without the text, therefore alternative 1 is recommended for use.

WEAVE

Four alternatives were evaluated for Weave signs, shown in Table 19.

Table 19. Weave Signs Evaluated in Study

Alternative 1	Alternative 2	Alternative 3	Alternative 4
			

Summary Findings for Weave

While the differences were not statistically significant, alternative 2 had higher comprehension than alternatives 1, 3 and 4, with 79%, 61%, 43% and 65%, respectively. Alternative 2 also performed the best on the multiple choice response, with 95% correct responses, over the 48%, 43% and 35% for alternatives 1, 3 and 4. Rankings were relatively low for all sign alternatives. Legibility distances varied significantly by alternative, with 506.73, 440.67, 490.80 and 473.71 for alternatives 1, 2, 3 and 4, respectively.

Recommendations for Weave

Alternative 2 is recommended for use.

REFERENCES

1. *Manual of Uniform Traffic Control Devices for Streets and Highways.* Federal Highway Administration, Washington, DC, 2009.
2. Dewar, R.E. and J.G. Ells. Comparison of Three Methods for Evaluating Traffic Signs. *Transportation Research Record 503*, Transportation Research Board, Washington, DC, 1974, pp. 38-47.
3. Dewar, R.E. Criteria for the Design and Evaluation of Traffic Sign Symbols. *Transportation Research Record 1160*, Transportation Research Board, Washington, DC, 1988, pp. 1-6.
4. Alicandri, E. and K. Wochinger. *Evaluation of Selected Potential MUTCD Signs*. Federal Highway Administration Report FHWA-RD-00-053, Washington, DC, 2000.
5. Katz, B.J., G.K. Rousseau, and D.L. Warren. *Comprehension of Warning and Regulatory Signs for Speed*. Proceedings of the Institute of Transportation Engineers Annual Meeting. Seattle, WA, 2003.
6. Katz, B.J., Dagnall, E.D., O'Donnell, C., and Emo, A. *Design and Evaluation of Selected Symbol Signs, Phase II*. Federal Highway Administration, Washington, DC, 2010.
7. Picha, D.L., H.G. Hawkins, and K.N. Womack. *Motorist Understanding of Alternative Designs for Traffic Signs*. Research Report 1261-5F. Texas Transportation Institute. College Station, TX, 1995.
8. Golembiewski, G., Katz, B.J., Dagnall, E.D., and Bertola, M.A. *Evaluation of Combined Lane Use and Destination Sign Alternatives for Overhead-Mounted Guide Signs on Multilane Conventional Road Intersection Approaches*. Federal Highway Administration, Washington, DC, 2011.
9. Desrosiers, R.D. Moving Picture Technique for Highway Signing Studies – An Investigation of its Applicability. *Public Roads*, Vol. 33, No. 7, Bureau of Public Roads, Washington, DC, 1965, pp. 143-147.
10. Zwahlen, H.T., X. Hu, M. Sunkara, and L.M. Duffus. Recognition of Traffic Sign Symbols in the Field during Daytime and Nighttime. *Proceedings of the Human Factors Society 35th Annual Meeting*, Santa Monica, CA, 1991, pp. 1058-1062.
11. Philips, B.H., J.E. Fox, and R.D. Peters. *Computer-Aided Optimization and Evaluation of Selected Signs*. Presented at the Transportation Research Board 77th Annual Meeting, Washington, DC, 1998.
12. Mahach, K.R., K. Wochinger, R. Marshall, and D. Eppich. Sign Simulator Validated in FHWA Study. *Public Roads*, Federal Highway Administration, Washington, DC, July/August 1999.