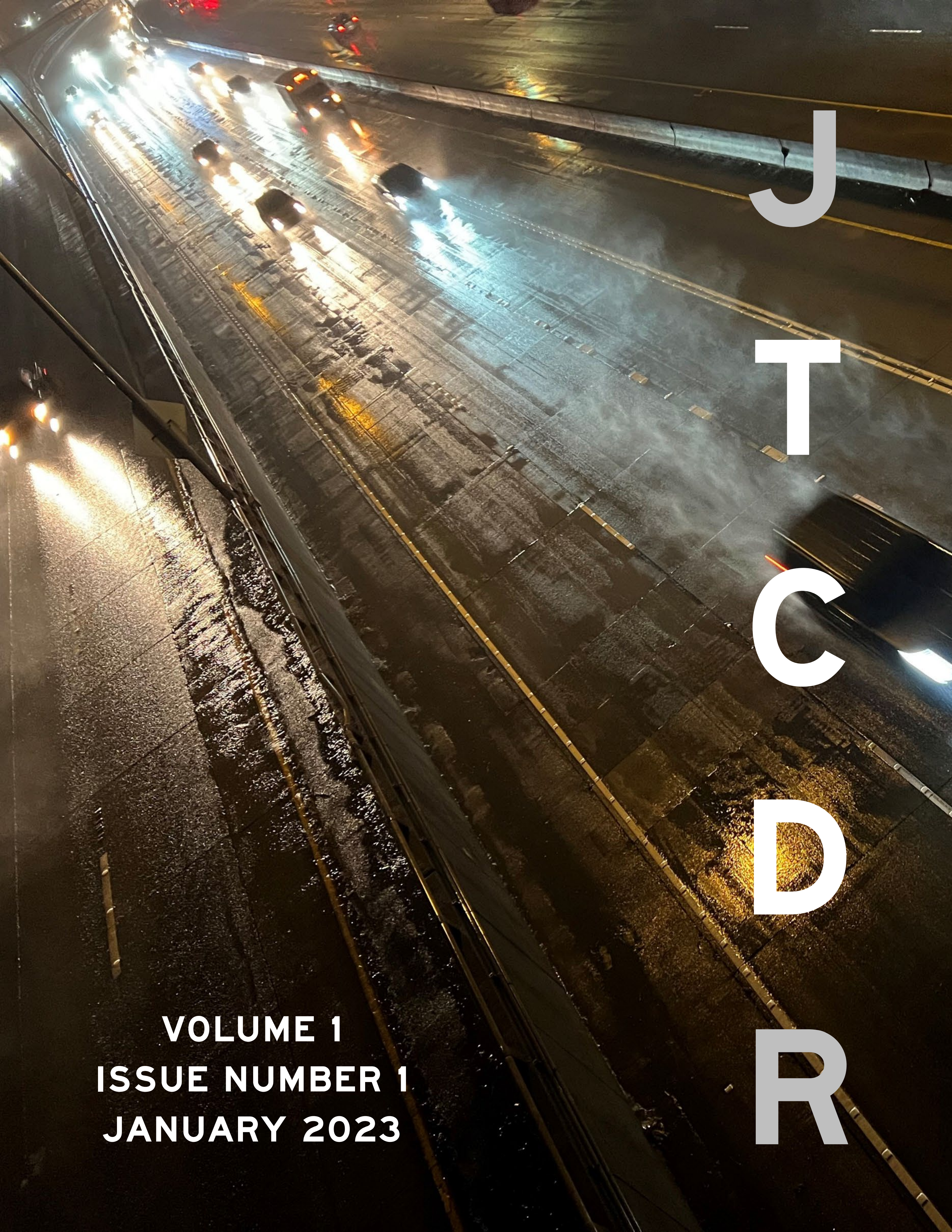

J T C D R

VOLUME 1
ISSUE NUMBER 1
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ON THE COVER

In Washington State, profiled plastic pavement markings are used extensively outside of the snow zones. This view of Interstate 5, from the Yesler Street overcrossing, illustrates the wet weather visibility benefits accrued on account employing tactile intensity in a marking pattern. These markings are typically more visible than conventional single-plane markings for both humans and machine sensors. Profiled markings also provide immediate discernible haptic and aural feedback to the vehicle occupants when tire contact is made. This distinctive pattern of sound is also readily apparent to occupants of other nearby vehicles and to other road users, including pedestrians, serving as a passive lane departure warning system.

In conjunction with raised reflective pavement markers installed according to the Washington State Department of Transportation's Standard Plans, this system of markings, supplemental markings, and delineation offers immediate benefits to human drivers, the driver assistance systems of today, and the emerging automated driving systems of the future.

JOURNAL OF TRAFFIC CONTROL DEVICE RESEARCH
JANUARY 2023

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JOURNAL OF TRAFFIC CONTROL DEVICE RESEARCH

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WHEN USED THROUGHOUT THIS DOCUMENT,
THE ABBREVIATION "TCD" IS INTENDED TO
STAND IN FOR THE TERM "TRAFFIC CONTROL DEVICE"

PUBLISHED BY
**THE NATIONAL COMMITTEE ON UNIFORM
TRAFFIC CONTROL DEVICES**

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VISTA POINTS

JOURNAL OF TRAFFIC CONTROL DEVICE RESEARCH
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JOURNAL OF TRAFFIC CONTROL DEVICE RESEARCH
VOLUME 1, ISSUE 1 | JANUARY 2023

FOREWORD

H. Gene Hawkins, Jr., PhD., P.E.
NCUTCD Chair

As Chair of the NCUTCD, I want to welcome you to the first issue of the Journal of Traffic Control Device Research. I am so pleased to see the NCUTCD produce this document and I look forward to the role this journal will play in future improvements to traffic control devices and the MUTCD. I see this journal making an important contribution to advancing traffic control device practices.

Traffic control devices may be the most important tool in the traffic engineer's toolbox. Traffic engineering is a challenging field that involves so much more than just engineering. A traffic engineer needs an understanding of engineering, human factors, psychology, law enforcement, civics, economics, public policy, and a gut feel for what may work (or may not work). Practitioners and the traveling public have many questions regarding traffic control devices. Will road users respond to a device in the intended manner? Does it improve safety for road users? Does it increase road worker risk for installation and maintenance? Does it require enforcement to work? How much will it cost agencies to implement? Does it complement and is it consistent with other devices already in the MUTCD? And so many more questions. No single effort can answer them all. There has never been enough information about traffic control devices and it is likely that there will never be enough. All we can do is chip away at the mountain. Each traffic control device evaluation represents one brick in a large masonry structure. As someone who has spent most of their career evaluating traffic control devices, I realize how difficult it can be to make study results available to others. I want this journal to provide an easier path to sharing traffic control device information.

I am the son of a traffic engineer. I have a vivid memory as a young boy of my father (who worked for the City of Houston) using one of my toy cars to practice a presentation on the benefits of a quick-drying marking material he wanted the city to implement. That demonstration by my father may be part of the inspiration for this journal. After becoming NCUTCD Chair, I challenged Bryan Katz, chair of the NCUTCD Research Committee, to create a journal that would focus on the practical aspects of traffic control device evaluations and provide NCUTCD members with better information for developing recommended changes to the MUTCD. This is not a new need. In 1962, my father's boss at the city was appointed to the National Joint Committee on Uniform Traffic Control Devices (a predecessor of the NCUTCD). Soon after, he offered the following thoughts in an issue of the Texas ITE section newsletter: "There has been some criticism in the past regarding new standards in the Manual and questions as to what basis was used for the development of these standards. There are probably reasonable grounds for this criticism where new standards have been decided upon by a majority of the vote of members of the Committee without the benefit of proper research or studies (author's note: this statement was made when the NJCUTCD was responsible for MUTCD content, FHWA assumed ownership of the MUTCD in 1971). There is unanimity of opinion among the current members of the Joint Committee that any further modification, changes, or additions to the Manual should be based on the results of very thorough research."

My goal is challenging the Research Committee to develop this journal was to find a way to publicize practical findings about traffic control devices without having to worry about journal impact factors, detailed statistical analysis, and some of the burdens that come with academic-oriented journals. While the name of the journal uses the word "research," you may note that I have not used that word to describe what we are looking for. I do not want potential authors to feel that a study has to be comprehensive to be included in the journal. Rather than call the contents of this journal research papers, I prefer to call them traffic control device evaluations. Every evaluation makes a contribution to the body of knowledge. Another brick in the wall so to speak (for you Pink Floyd fans). With this inaugural issue behind us, I hope that you will think of an evaluation you have done and will submit it for possible inclusion in a future issue. With your assistance, we can use this journal to help fulfill the goal established by Mr. McEachern in 1962 to base all future changes to the MUTCD on factual data.


PG

EDITOR'S WELCOME

Bryan J. Katz, PhD., P.E., PTOE, RSP$_{2I}$
Executive Editor & NCUTCD Vice Chair

It is with great enthusiasm that I welcome you to the inaugural issue of the Journal of Traffic Control Device Research. The Journal represents a vision that Dr. Gene Hawkins and I established when we were both elected to our positions as officers on the NCUTCD. Our vision with this journal is to increase the dissemination of research and evaluations through publishing technical papers and case studies related to the research and evaluation of traffic control devices.

The editors intend to publish rigorously-sound articles based on scientific study that are also practical in nature, advancing the state-of-knowledge in TCD design, placement, safety, operations, and maintenance. As Dr. Gene Hawkins notes in his foreword "Traffic control devices may be the most important tool in the traffic engineer's toolbox".

When I teach Transportation Engineering classes at Virginia Tech, I tell students that it is important to remember that TCDs are the primary method that traffic engineers communicate information to motorists. Engineers can develop new and innovative roadway design configurations. Engineers and researchers can test their operations through modern microsimulation techniques to prove that the innovative design has the potential to reduce delay and improve operations. However, if road users don't understand what they are supposed to do and how they are supposed to navigate the facility, the effort is wasted. In more simple terms, as one of my colleagues says, "If you can't sign it, don't design it." Human factors is a critical consideration when it comes to TCDs and this journal will feature articles that address considerations related to road user comprehension and road user behavior when interacting with TCDs.

The *Manual on Uniform Traffic Control Devices* (*MUTCD*) is an ever-changing document that is updated periodically to address new advancements and knowledge in TCD design and implementation. It is our hope that this Journal will provide information that helps to provide data-driven decisions for future changes in the MUTCD.

This journal represents the hard work of the authors as well as the NCUTCD Research Committee. Specifically, I would like to thank Scott Kuznicki and Mike Tantillo for their work in assembling this inaugural journal for distribution.

THE STEADY BEACON

Scott O. Kuznicki, P.E.
Managing Editor

What does this mean? Perhaps you have found yourself asking this question upon approaching a sign, marking, or other traffic control feature. Occasionally, you might encounter a TCD that simply appears to be malfunctioning. Sometimes, it's a steady beacon, an indication that most traffic engineers might agree means absolutely nothing other than a failed flasher. To the general public, the steady beacon could mean anything.

Interpreting the meaning of functional and errant traffic control devices isn't just a job for the traffic engineer. Rather, the work of the traffic engineer can and must ensure that the meaning and applicability of traffic control devices remains clear to road users even when failures of function and interpretation occur, particularly for critical devices.

But what about failures of logic? Meeting the goals of visibility and comprehension requires attention to the uniformity of TCDs. Uniformity is achieved when there is an expectation of logical continuity through consistency and differentiability, such that specific devices have specific meanings. If correlation between messages and geometry is not achieved, road users will observe a variety of logic mismatches, ranging from the use of yellow flashing indications to the variety of signs and arrows used with option lanes to the use of numerals from unapproved fonts, all as meaningful as a steady beacon.

Often, these seeming oddities are based on research, some of it quite compelling! While research may show that demonstrated user preference favors one approach over another, more than occasionally by a slim statistical margin, the astute traffic engineer will seek to harmonize heuristics, logic models, and past and common practices in art of traffic engineering. This necessarily means that we are eager to anticipate the human factor, going beyond the all-important discipline of human factors in an effort to understand more than "What does this mean?" We must ask, also, "*Why* have we done this?"

What we see in the field is an indication of traffic engineering expertise and a reflection of the diligence of the people who play a role in selecting, designing, erecting, and maintaining traffic control devices. Improving the user experience drives our research of materials, fabrication, tools, visibility, durability, comprehension, and the all-important user response. We ask questions and seek these answers for the sake of the road user.

SUBMISSIONS TO THE
JOURNAL OF TRAFFIC CONTROL DEVICE RESEARCH

Submissions to the JTCDR are accepted at the web site of the National Committee on Uniform Traffic Control Devices, http://ncutcd.org on any web browser. Refer to the call for papers and submission guidelines for more information.

Future calls for submissions and papers will address pavement marking and delineation research, specifically regarding harmonization of desired characteristics for human drivers, advanced driver automation systems, and highly-automated vehicle systems.

While many journals typically accept research papers summarizing the results of experimentation or describing general methodologies, the Journal of Traffic Control Device Research is also home for a wide variety of technical and philosophical perspectives related to the disciplines of traffic engineering, transportation safety, and human factors engineering in transportation. The list below identifies some of the types of technical materials the editors are seeking for future issues.

- Research Compilation and Syntheses of Practice
- Practices Evaluations and Project Overviews
- Evaluations of Novel and Existing TCDs
- Human Factors Performance Evaluations
- Safety Outcome Evaluations
- Technology Applications and Integration with Automated Driving Systems
- Research Proposals for Innovative and Evolving TCDs
- Historical Perspectives on Traffic Engineering and the Development of TCDs
- Current Perspectives on Issues Related to TCDs and Human Factors Research

The chief goal of this journal is to capture and retain knowledge in an accessible format. The greatest knowledge we can obtain consists of reflections and insights from those who have spent decades learning about this work. These pioneering leaders developed the principles, methodologies, and systematic tools that traffic engineers use today to implement and evaluate the performance of traffic control devices.


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WALK

JOURNAL OF TRAFFIC CONTROL DEVICE RESEARCH

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PAPER 001

Tucson BikeHAWK

Adapting the Pedestrian Hybrid Beacon to Assist Bicyclists in Crossing Arterial Streets

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INTRODUCTION

The Pedestrian Hybrid Beacon (PHB) or HAWK has been successfully used by communities around the nation to facilitate safe, convenient crossings of busy, high-speed roadways by pedestrians since its inclusion in the 2009 edition of the Manual on Uniform Traffic Control Devices (MUTCD). While not excluding their use, standard PHBs have never explicitly accommodated another large user group in need of the same facilitation to cross arterials: bicyclists. In 2012, the City of Tucson began efforts to modify select PHBs to allow for the clear and safe crossing of both user groups.

Starting in the 1980s, the City of Tucson shifted its focus from simply providing bike lanes along arterial and collector roadways to identifying existing residential streets that could be enhanced to provide a network of calm, low-stress bikeways. Having identified these routes (now termed bike boulevards), the city endeavored to improve this network by reducing automobile traffic, encouraging bicyclist use, and most critically, addressing how to safely and conveniently cross major streets where they intersect these bike boulevards.

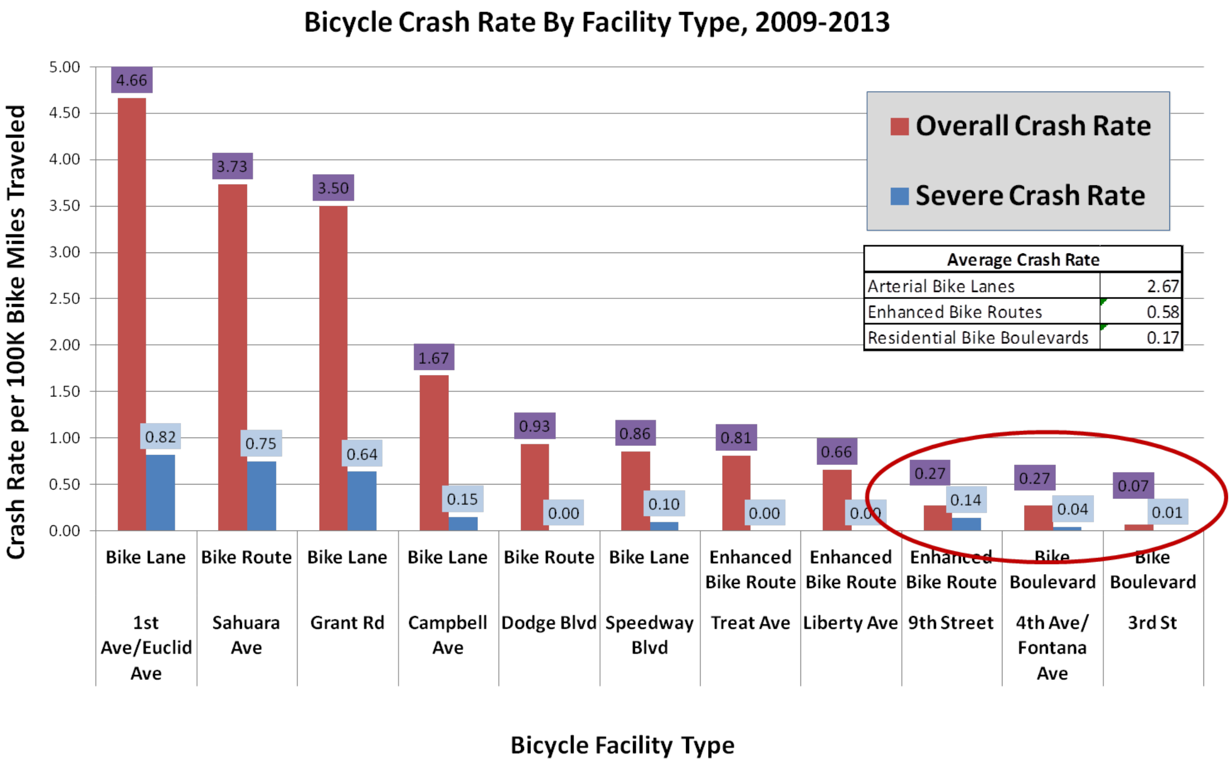
BACKGROUND

Bicycle boulevards function as residential streets along cycling “desire” lines designed to prioritize bicycling. The bicycle boulevard network serves as the backbone for biking in the Tucson region. Bicycle boulevards support several community values, including improving the health of Tucsonans, and providing safe and equitable transportation options. The Tucson Department of Transportation and Mobility has identified over 200 miles of existing and future bicycle boulevards along over 60 corridors that improve connectivity to schools, parks, libraries, commercial zones, County bike paths and other key destinations.

Bicycle boulevards typically include the defining features and traffic engineering tools to:

- Lower residential speeds with special 20 mph limits posted
- Traffic control devices and designs to reduce or eliminate “cut-through” arterial traffic desires
- PHBs to assist walkers and cyclists in crossing arterial streets in ease and safety

Bicycle boulevards vary in character to reflect the unique neighborhoods they travel through. Most importantly, however, they experience a significantly lower crash rate compared to facilities with arterial bicycle lanes.



While traditional traffic signals can sometimes be utilized as a method to provide safe crossings, they have the undesirable effect of attracting traffic to the residential streets they serve, increasing car traffic, and ultimately running contrary to the inherent purpose of bicycle boulevards.

In Tucson, prior to the implementation of the Bike HAWK, many crossing locations already had a Pedestrian Hybrid Beacon (PHB), alternatively known as a HAWK (**H**igh intensity **A**ctivated cross**W**al**K**), to assist crossing pedestrians. Federal studies noted that HAWK crossings have a consistently high driver yielding rate and are an approved traffic control device (use and operation detailed in "Signals" part 4 of the Manual of Uniform Traffic Control Devices (MUTCD)). Methods on how to achieve the same excellent driver response and facilitate bicycle crossings was undertaken by the City of Tucson and Pima Association of Governments (PAG), the Metropolitan Planning Organization for the Tucson region, to improve the operation and safety of the bicycle boulevard concept. The design was ultimately named the BikeHAWK.

A key to the BikeHAWK's success is that it is designed to match the observed behavior of bicyclists crossing at locations with existing HAWKs. The conversion of a HAWK into a BikeHAWK operation is easily accomplished. The first BikeHAWK was installed in 2012, with many currently installed throughout the city and more planned for or in design thanks in part to a new, voter-approved bond program.

The following section explains Tucson's experience with the BikeHAWK design, which uses a combination of MUTCD-approved signs, signals, and markings to guide bicyclists through the intersection of bike boulevard residential streets and arterial streets.

PURPOSE

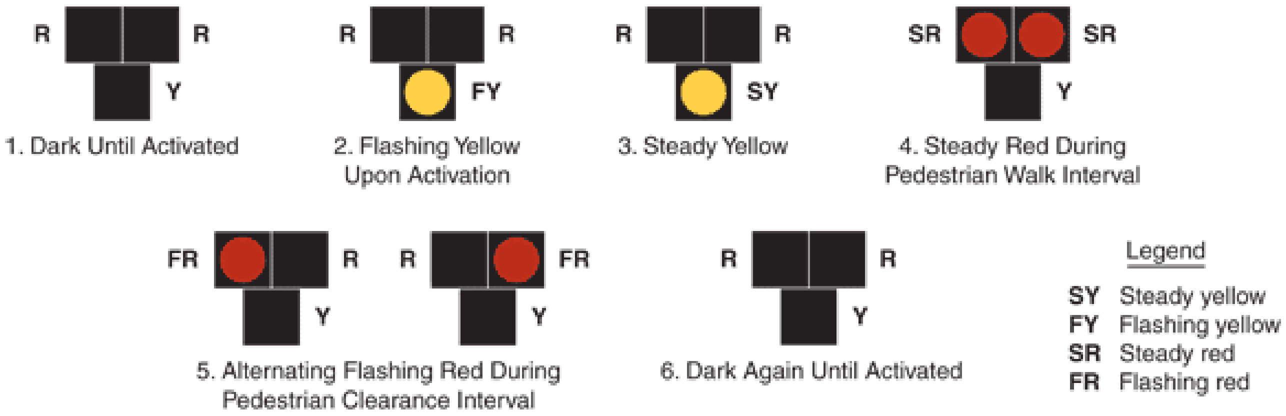
As the MUTCD notes, the PHB or HAWK does not control a whole intersection, but rather controls only a crosswalk at an intersection, like other pedestrian crossing beacon devices. As a result, bicyclists using a PHB find that for one direction of travel they are not on the same side of the road as the PHB. As previously noted, the BikeHAWK design took a human factors approach, observing bicyclists' behavior at a number of existing HAWK crossing locations. The BikeHAWK design was then developed by trying to match what the crossing bicyclists actually do to help further ensure high compliance and safety.

METHOD

Each entrance to the BikeHAWK on the low volume residential street has a clearly marked, two-way separated contra-flow bike lane painted green. Vertical separation is provided by a channelized curb and flexible delineator posts. This design technique slows vehicles and keeps the motor vehicles away from the entrance to the BikeHAWK. The green separated bike lane legitimizes the observed, or normal, movement by the approaching bicyclist frequently from the near center of the residential street toward the BikeHAWK crossing, regardless of whether the bicyclist is on the left side or right side of the residential street. The green lane guides bicyclists to the proper position to activate the beacon at a curb-side pushbutton allowing the bicyclist to avoid dismounting to use the pedestrian pushbutton on the sidewalk. The separated contra-flow bike lane also narrows the width of the residential street at the major street intersection which provides the added benefit of traffic calming on the residential street.

At the crossing point itself, bicyclists see adjacent to the high-visibility crosswalk an eight-foot wide high-visibility green path designated for their use. The bicyclist is directed to observe the pedestrian signal (MUTCD R9-5 sign: [BIKE SYMBOL] USE PEDESTRIAN SIGNAL). The BikeHAWK timing is identical to the PHB operation. After the normal YELLOW clearance warnings and optional clearance buffer the BikeHAWK shows solid RED indications to the arterial traffic and a WALK indication with R9-5 signs for the bicyclist and pedestrian, sequence 4. When the PHB moves to the flashing RED interval, the pedestrian WALK indication becomes the flashing DON'T WALK clearance interval, sequence 5. After a second optional buffer period the beacon returns to the dark mode again, until reactivated. (source: MUTCD 2009 Signals part 4, Figure 4F-3)

Figure 4F-3. Sequence for a Pedestrian Hybrid Beacon



In order to provide further guidance to the bike rider and discourage late entries into the crossing a supplemental sign was developed to further explain the operation. In Tucson, a dynamic supplemental illuminated sign was developed since word messages are MUTCD allowed to inform and/or educate roadway users of regulatory requirements. The supplemental sign is coordinated with the pedestrian signal circuit and reads orange BIKES WAIT or white BIKES OK depending upon the appropriate interval of the PHB crossing. BIKES WAIT is illuminated during the PHB dark period and the solid RED period. When the pedestrian is shown a WALK indication, the supplemental illuminated sign displays a BIKES OK indication. The supplemental illuminated sign then displays a flashing orange BIKES WAIT during the pedestrian clearance interval and rests in solid BIKES WAIT when the PHB is resting in the dark mode and the pedestrian signal rests in the DON'T WALK HAND.

As previously mentioned, the sign was not required since the MUTCD approved R9-5 is available, however the city chose to provide the additional dynamic safety message under the authority granted by the MUTCD part 2B.02 where other regulatory messages may be developed to aid the enforcement of other laws or regulations.

Even though the majority of the bicyclists entered the crossing area at the PHB in a nearly identical fashion, they left the crosswalk using a variety of paths. Thus, the final design of the BikeHAWK encourages the better of the various exiting behaviors via signs and markings. The same green separated bike lane that serves the entering bicyclists is also used by exiting bicyclists. As the bicyclist leaves the separated bike lane they normally gravitate back to the center or just right of center on the narrow residential street. The two-way separated bike lane segment allows bicyclists to ride a short distance in the contra-flow direction before crossing; this return movement is similar to a left turn into or out of a driveway on the side street and does not need any special warning; even so, “sharrows” are installed to provide warning. At the end of the contra-flow lane, signs advise bicyclists that they are about to be riding in the wrong direction and that they need to ride the appropriate direction with traffic. To provide further protection to the cycling traffic as they return to the residential street, drivers are not allowed to turn-right-on-RED from the arterial onto the residential street. Initially, there was a concern about bike riders having to enter and leave the contra-flow lane, however safety issues did not materialize since the bicycle boulevard residential street was a small, low speed 20 mph street and the cyclists frequently rode near the center of the street away from the parked cars making entry into and exit from the contra-flow green lane a convenient and safe maneuver.

RESULTS

In summary, the key elements of the BikeHAWK include:

- A short, separated green contra-flow bike lane to position bicyclists into an area delineated by flexible posts.
- Placement of curbside signal detection buttons in easy reach of bicyclists.
- Use of green pavement markings in a high-visibility crosswalk pattern adjacent to the high-visibility white crosswalk.
- MUTCD-approved signing advising cyclists to observe pedestrian signals (R9-5).
- MUTCD-approved signs encouraging bicyclists to ride with traffic after the crossing has been completed and it is safe to make the maneuver (R5-1b and R9-3cP).
- Supplemental illuminated sign to further support the (R9-5) sign and assist the rider in crossing

Because the design matches bicyclists' observed behavior and current traffic laws, along with the MUTCD, Tucson has found that very little education has been necessary to achieve high compliance by all road users.

See news video report, *Stop lights can... RUIN a street for bicyclists?* YouTube https://www.youtube.com/watch?v=Dk8uhfFCtM0

CONCLUSIONS AND OTHER CONSIDERATIONS

The BikeHAWK has been well-received by the bicycle advisory groups, law enforcement, and pedestrian safety and neighborhood support community groups. Back in 2012, local news media interviewed bicyclists at one of the busier BikeHAWKs, and all bicyclists indicated they understand and appreciate the new traffic control device. The most common theme in their response is that it makes them feel safer when crossing the busy arterial street. Peak-period pedestrian and bicycle counts conducted at the BikeHAWK, which serviced a transit stop, community college and medical center were done by the Pima Association of Governments. During their normal counting program, it was noted that:

- 96% of the riders use the BikeHAWK as designed.
- 100% of family riders with children or children alone use the BikeHAWK;
- 94% of the crossers were bicyclists and 6% were pedestrians.
- The device was easily understood by all users and bicyclists followed the designated paths with ease.
- There was the normal high level of driver compliance to the crossing device, especially at the high-speed crossings in the range from 97% to 100% yielding behavior by drivers.
- 50% of riders using the BikeHAWK were males, 46% were females, and 6% were children. (This level of female ridership is significantly higher than the average regional percentage and is considered an indication of perceived safety)

Late entries by the pedestrians with the current pedestrian and countdown signal happen often at traditional traffic signals. The same behavioral issue is occasionally true for the PHB crossings. Thus, it was felt that cyclists were better informed of the clearance interval requirement to not enter the crossing by the supplemental dynamic BIKES WAIT and BIKES OK illuminated sign that was powered in parallel with the pedestrian signal circuit.

Initially, it was attempted to time the supplemental bicycle illuminated sign separately from the pedestrian signal to provide a longer bicycle crossing interval. However, common timing of the illuminated bike supplemental sign with the pedestrian signals was found more desirable. The common operation reduced pedestrian error danger if a pedestrian inadvertently presses the curbside bicycle button and only receives the shorter clearance crossing time.

Pedestrian and bicycle compliance jumped from approximately 70% to over 90% when the city converted the operation to a "HOT" command operation. This change in operation significantly improved traffic operations by reducing the false stop for an empty crosswalk since the pedestrian or cyclist crossed during a natural gap. The hot button operation had no significant impact upon the level of service for the vehicular movement along the arterial which remained in the upper LOS (level of service) ranges.

To date, there have been no reported bicycle or pedestrian crossing fatal crashes or injuries at a BikeHAWK installation. One never knows what is going to happen tomorrow, but these devices have been in successful operation for the last 10 years.

The Tucson BikeHAWK is a recognized as a best practice and in the University of North Carolina Safety Research Center - FHWA Pedestrian and Bicycle Information Center, https://www.pedbikeinfo.org/resources/resources_details.cfm?id=4950

Human factors have played a significant role in the design of the BikeHAWK traffic control device technique. It is better to design to what the people will do, not what they are supposed to do. The BikeHAWK design matched the behavior of cyclists currently using the PHB when crossing an arterial. It was observed pedestrians, especially children, push all the buttons on the corner. The pedestrian dangers of receiving a shorter bicycle clearance time accidently instead of the full pedestrian clearance time if the wrong button was pushed was eliminated with the common operation. This parallel circuit operation resulted in no ill effects for the bicycle or arterial LOS. The placement of the supplemental illuminated sign provided further information to the assist the cyclist in following the pedestrian signal indication.

In addition, people respond well to "immediate response" and the city has now removed nearly all the PHB units from a background double cycle synchronization program and operates them with a "HOT" demand button. This technique of providing immediate recognition of a crossing request gives the system credibility, reduces delay to the pedestrians, who frequently cross when a natural gap occurs, and drivers no longer are forced to wait at an empty crosswalk.

RECOMMENDATIONS

The Tucson BikeHAWK employs traffic control devices and techniques that are already approved by FHWA and the MUTCD (note: the green pavement marking currently requires interim approval) and are widely understood by the public.

The green two-way separated bike lane section further protects the bicyclists by identifying their area and keeping vehicles from encroaching into the bikes' area. In addition, the flexible posts were observed to result in slower vehicular turning movements on to and off of the residential street, creating an additional traffic-calming effect for the residential street and crossing protection.

The Tucson region has over 150 PHBs or HAWKs in operation since their initial installation in 2000, including 31 BikeHAWKs currently in operation since their first installation in 2012. Another 18 BikeHAWKs are programmed to be in operation by the beginning of 2023 and 34 more programmed by Fiscal Year 26.

Most importantly, the Tucson BikeHAWK technique meets the current MUTCD 2009, matches the natural behavior of the bicyclists and pedestrians, helps maintain residential neighborhood traffic calming, and is available for use by the profession now.

With bicyclist and pedestrian traffic fatalities growing alarmingly high in recent years, innovative and effective treatments like the Tucson BikeHAWK are in desperate need. The Tucson BikeHAWK is another technique to get everyone home safe and sound.

JOURNAL OF TRAFFIC CONTROL DEVICE RESEARCH

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PAPER 002

Human Factors Evaluation Methods for Traffic Control Devices

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INTRODUCTION

The U S Manual on Uniform Traffic Control Devices (MUTCD) outlines the steps in a process for requesting and conducting experimentations for new traffic control devices (TCDs). This process should contain a detailed research plan to include, if appropriate, both before and after studies as well as quantitative data describing the performance of the experimental device. However, no instruction or guidance is provided in the MUTCD with regard to specific evaluation techniques. Due to the critical role of human factors in TCD design and effectiveness, it is essential that evaluation techniques be properly conducted and be sensitive to road user capabilities and limitations.

Many currently used TCDs were developed several decades ago with little or no scientific data to support their design or effectiveness. Shapiro, et al. (1) in 1987 indicate that previously many TCD standards were based on subjective opinion, often that of those on relevant committees responsible for the design of devices such as symbol signs. Their research study identified standards that lacked a research basis or were in conflict with research studies. This was the experience of one of the authors who was a voting member of the U S National Committee on Uniform Traffic Control Devices in the 1970s. Additional research was recommended by Shapiro, et al. for 17 TCD standards.

In recent decades much more effort has been spent on the scientific evaluation of TCDs, especially those new ones being introduced into a system. There are a number of criteria for an effective TCD. These include comprehension, legibility (both distance and glance legibility), conspicuity, response time, and learnability (how well the meaning of a TCD can be remembered). Their relative weightings have not been determined, but some are more important than others. A survey by Dewar (2) asked traffic engineers and sign experts in The US, Canada, Australia and New Zealand about the importance of several criteria for the design and evaluation of traffic sign symbols. The most important were comprehension, legibility and conspicuity. It is appropriate to include at least the most important ones (comprehension and legibility distance) when evaluating these devices.

If a new symbol sign message is required the first step is to determine if a current one is in use elsewhere (another country or state), and if so whether it has been shown to be effective. If an effective one is found, there may be no need to design anther version.

METHODOLOGY

Methods can be broadly categorized as either field (on-the-road or on a test track) or laboratory measures, including driving simulators, surveys and focus groups. Laboratory studies are usually done with artificial stimuli in a test laboratory or classroom, with one subject or small groups, depending on the nature of the test procedure. Computers may be used to present stimuli (e.g., signs, signal configurations). Some laboratories use driving simulators to mimic more effectively the real world of driving. Simulators can be expensive and fail to replicate the road world of driving unless they are motion-based.

Planning and evaluation of TCDs should include the following steps.

1. Problem Identification - observation of road user movements, vehicular studies, crash records, etc.
2. Development of a Research Question - a hypothesis that can be tested in the study (e.g., will a new device elicit the specified behavior; is design A better than design B?).
3. Design the Evaluation - identification of a sequence of before-after studies, conducted over time or across different locations, a laboratory study or survey to test for comprehension and legibility. In the case of the former approach consideration should be given to a “control” study, at a similar location or locations where no treatment has been applied.
4. Finalize the Evaluation Plan – e.g., consider methodological trade-offs as constrained by time and budget
5. The conduct of the evaluation must be based on the following:

- Data Collection Plan - observation of appropriate events to ensure valid measurement of effectiveness
- Determination of Sample Size and composition - a sufficient number of observations is required to ensure statistical suitability of results and an adequate sample of road users - novices, seniors, both genders.
- Determine Data Collection Periods - periods of data collection (time, day of week, weather) must be consistent between before and after studies for field measures.
- Statistical Analyses - testing for statistical significance to determine the likelihood that any observed change was caused by the treatment
- Assess Practical Difference - a calculated “statistically significant” result may be too small to represent a practical effect
- Evaluate the Results – e.g., the cost-benefit analysis is useful to determine whether a TCD is cost-effective in terms of collision reduction or changes in road user behavior.

A variety of methods are available for the evaluation of TCDs (3,4). Dewar and Ells compared three methods of sign evaluation – driving toward the signs on a rural road at 30 or 50 mph, a modification of this procedure where subjects drove at 17 mph toward signs 1/3 the standard size, and a laboratory measure of reaction time to the same signs. The measure was the distance, or time, for drivers to classify and to identify the sign messages. Results showed the three methods were closely related.

The use of computers and driving simulators allows the introduction of additional variables such as loading tasks (e.g., count backward from 100 in threes, respond to a target shown at random on the dashboard), vehicle handling characteristics, and environmental conditions (e.g., darkness, rain). However, simulators can induce motion sickness, especially for older drivers. Laboratory measures include drivers viewing images of TCDs to establish comprehension or legibility, as well as “paper-and-pencil” tests to measure comprehension, preferences, etc.

Comprehension

A number of methods are available for determining how well users understand TCDs. The procedures include writing the meaning of a TCD on an answer sheet, selecting the most appropriate answer in a multiple choice (MC) format, rating the clarity of the device’s meaning,

or indicating the action to be taken in response to the TCD (e.g., which way a driver may turn when seeing a configuration of signals or a pavement marking). Having subjects write out the meanings of TCDs is the most time-consuming laboratory technique, but it is the preferred one, as it provides the richest data, allowing, for example, evaluation of the nature of the errors and confusions among symbols within the same signing system. The MC test can also be used (e.g., which of 4 signs means added lane? which of 4 answers is correct for this symbol? or which of 4 actions is allowed when this marking is seen?). It is essential with MC tests that reasonable “wrong” answers are used in order to avoid correct guessing. One mistake often made by those using this method is failure to correct for guessing. If there are four choices in the MC test, then a subject can get ¼ correct just be guessing, as chances of being correct and one in four. So a correction needs to be made. The formula for this is:
$FS = R - W/(N - 1)$
FS= "corrected" score
R= number of items answered right
W= number of items answered wrong
N = number of options (alternatives)
For example: assume a 40-item sign test where the subject gets 28 correct and 12 wrong. The corrected score would
be 28 – 12/3 = 24 correct

Another method to gauge comprehension is the confusion matrix. This involves recording the number of responses that were correct and those wrong responses that were given another meaning. For example, an added lane symbol may be thought to be added lane, merge, yield, one way, or stop. The table below, with imaginary data, provides an example of how this method might be used. It can be seen that the added lane sign was only confused with a merge sign. The frequency of these confusions can provide insight into why errors are made and can lead to sign redesign if needed.

		Response			
	Added lane	merge	yield	one way	stop
Sign					
Added lane.	78	15	7	0	0
merge	2	90	6	1	1
yield	1	2	94	1	2
one way	0	3	0	97	0
Stop	0	0	2	0	98

In a comprehension study of all the symbols in the 1988 US MUTCD (5) the most common wrong answer was MERGE.

Comprehension of roundabout traffic control devices included in the 2009 MUTCD, (e.g., Figure 2D-8 destination signs and Section 3C.01 pavement markings) was tested in a laboratory study (6) to ensure their understanding by road users. The tested devices included guide signs, regulatory/warning signs, central island treatments, and pavement markings

Participants were told to follow a route to a specific destination and were shown sequential pictures of a roundabout approach and entry scenes. They made choices (and indicated their confidence in each choice) as to the correct-inner circle lane for their intended destination. Figure 1 below depicts an example scene in which drivers would designate their choice of lanes (A or B). The applied TCD measure of effectiveness was the device configuration that produced highest proportion of correct lane choices.

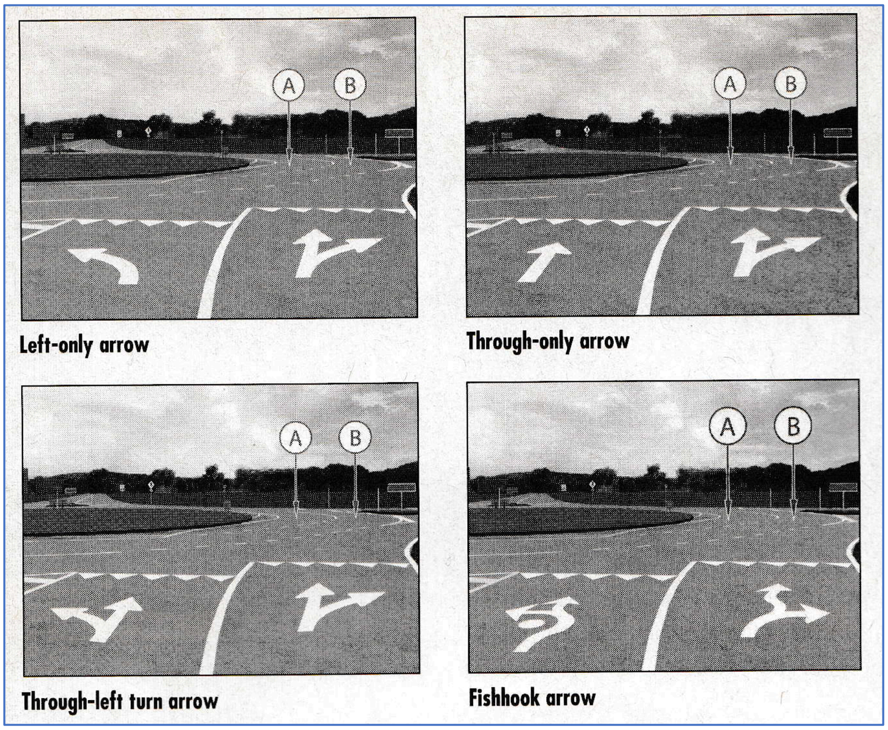


Figure 1. Example approach scene stimuli: participants asked to choose lane A or B

In addition to determining the proportion of correct line choices associated with areas markings, a structured interview procedure was also applied. Participant responses to the question, “What does this device tell you?” were insightful regarding driver interpretations of tested devices.

The value of appraising traffic sign symbols by experts and applying three ergonomic design principles to traffic sign comprehension has been demonstrated by Ben-Bassat, et al. (7,8) who had 27 human factors and ergonomics experts from 10 countries evaluate 31 conventional signs and 1-3 alternative symbol designs for each of these signs for the~~ir~~ compliance of the signs with the three ergonomic guidelines of message-symbol compatibility, standardization, and familiarity. The experts assigned higher ratings to the alternative designs for 19 of the 31 signs.

Legibility

Legibility measures to determine the distance at which a sign message is legible for signs may have the driver drive or be moved toward the sign (3) or the sign moved toward the driver (9). One can also gradually increasing the size of the image on a computer screen until the subject can describe its contents or identify the message (5). Legibility of traffic signs was studied by Khavanin and Schwab (11) who had press a button when they could read signs while driving toward them.

Glance legibility can be gauged by presenting the TCD for a very brief duration to find the proportion of drivers able to identify the message at a specified brief interval, or by increasing the duration of the presentation until the driver can identify the message (5).

Perception-response time

The speed with which drivers can interpret a TCD, especially signs, can be measured by displaying a photo, computer image or slide of the TCD and recording how quickly the driver identifies it by naming the message (being recorded by a voice key) or pressing a button to indicate - yes or no - whether the sign shown did or did not correspond with a name of the sign given in advance. Using this method Ells and Dewar (10) found that symbol signs were recognized faster than word signs.

Conspicuity

Conspicuity, how noticeable a device is in the road environment, can be determined for example by noting how many drivers notice the sign on the road (12) or timing how long it takes to detect it when displayed among a number of other signs, or a visually cluttered roadway scene, presented in a photo, on a computer screen (5).

Learnability

To determine how readily a TCD can be remembered subjects can be told the meaning of the device (e.g., a sign or pavement marking), then tested weeks or months later to see if they remember the meaning.

On-road measures

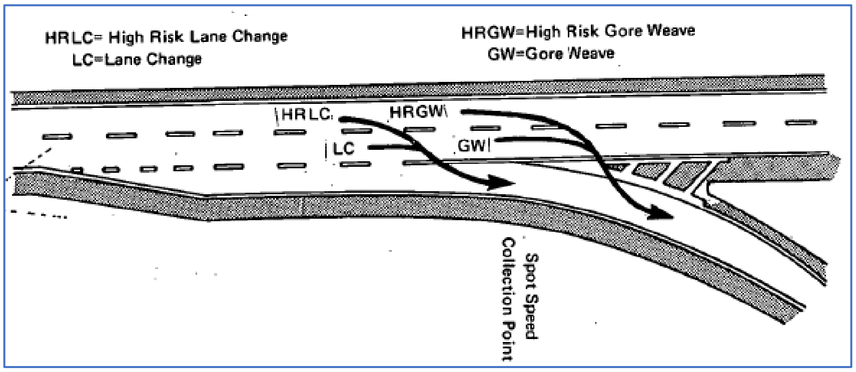
Performance of a TCD on the road can be assessed by observing driver, cyclist and pedestrian behavior. The TCD at a control site or sites with similar geometry and traffic volume is needed for comparison with the device of interest, or a before-and-after study can be done to determine the effectiveness of a new or changed TCD. On-road measures may involve distance needed to detect and identify target signs or signals or measuring time taken to changing lanes in response to a pavement marking. Instrumented vehicles are sometimes used to record speed, steering, braking, placement on the road, etc. Driver behavior (e.g., illegal turns, running red lights) or pedestrian behavior (e.g., late entry to cross an intersection, jaywalking) can be observed at specific sites using video recording or personal observations. The advantage of video is that it can be viewed a number of times, if necessary, and scored by two recorders. Any discrepancy between these two can be resolved by having a third person score the data.

With on-road measures care must be taken to observe behavior not only at the location of interest, but at control locations with similar road configuration, traffic volume, etc. in order to know whether any new or changed TCD changed road user behavior. In addition, factors such as time of day, day of the week and season need to be controlled.

Eye-movement measures can also be used on the road or in the lab to find out how effectively or quickly drivers detect a TCD as they search the road environment or a display shown on a screen. This can provide information on how sign design or placement attracts a driver's attention and what part of the sign is viewed first. The latter may have implications on where to place specific information on the sign panel.

Field observational studies of road user behaviors provide detailed and unique insights regarding the effectiveness of TCDs. Both the measures (observed data variables) and the methods (how relevant variables are observed) are critical to the conduct of any field study. The most commonly applied measures, vehicle speeds and speed-profiles, are gathered using manual-stopwatch timing, video burst sampling, or pavement instrumentation. Vehicle lateral roadway position and vehicle erratic maneuvers are obtainable via video. The following are examples of TCD evaluation methods apply to operational measures to determine the effectiveness of designated TCDs:

Lane-change behavior approaching interchange with diagrammatic guide signs. The objective is to establish the validity of selected Measures of Effectiveness (MOEs) for guide signs that comply with the MUTCD. These MOEs comprise an implementable tool by which traffic engineers can judge the effectiveness of new guide signs. For example, in one study (13) the specific lane-change behaviors illustrated in the figure below were videotaped, and drivers making these maneuvers were stopped by State Police and requested to complete a 4-page questionnaire.



Driver behaviors indicative of potential guide signing issues

The level of hazard associated with each of the above noted lane change behaviors was identified utilizing over 300 driver surveys, each associated with its respective lane-change behavior. The questionnaire analysis addressed the following driver human-factors issues:

- Driver information processing - including survey items that confirmed the related nature of the vehicle action (e.g., sign detection, interpretation, information retention).

- Driver predisposition – including sources of variance (such as biographical, risk-taking, driver experience, and comfort factors) capable of influencing a driver's response to guide signs.

The evaluation tool is applied by practitioners to estimate hazardous operational conditions resulting from potential guide sign deficiencies as follows.

Gore Weave (and High-Risk Gore Weave) Guide sign issues may be associated with driver information processing:

- Greater sign information processing difficulty with all guide signs on interchange approach.
- Less certain of action response to all guide signs on approach.
- Less time available to read and respond to intermediate exit direction sign.
- Lower preference rating for intermediate exit direction sign.
- Less likely to detect at least one guide sign.

Driving Slowly Guide sign issues may be associated with driver information processing as follows:

- Greater information processing difficulty with at least one guide sign.
- Lower preference rating of gore-located exit direction sign.

Late Lane Change Guide sign issues may be associated with driver information processing as follows:

- Greater information processing difficulty with at least two guide signs.
- Less certain of action taken to gore-located exit directions signs and one advance sign

Speed profiles in advance of warning signs can be assessed with pavement instrumentation capable of recording vehicle speed distribution data when installed at critical distances in advance of warning signs to be evaluated. Necessary considerations are AASHTO-defined driver stopping sight distances, e.g., requirements for driver detection, recognition, and response to a traffic control device. Speed data gathered at this advanced distance are useful to define a baseline condition against which speeds influenced by tested TCDs can be compared. Speed profiles between the advance placement and the location of the targeted roadway condition provide insight regarding the effectiveness of the tested device.

The deployment of roadway instrumentation and timing of data collection intervals are based on specific conditions (e.g., weather, traffic volume) where the warning signs are intended to address. Separate speed profiles should be developed for targeted drivers (e.g., higher speed drivers). Supplementary driver questionnaires are useful to address critical issues such as driver observations and perceived credibility of the warning signs.

An example speed profile in advance of icy bridge warning signs is the study by Hanscom (14). The critical human factors issue addressed by this study was that bridges typically freeze before roadways; therefore, icy conditions may be unexpected. Designated speed-collection points permitted an assessment of the following:

- baseline driver speed absent influence of the bridge,
- driver speed as the bridge was clearly in view,
- speed at the critical bridge entry point
- maintained speed on the bridge.

Measures of driver behavior at roundabout signs and markings have included observation of erratic maneuvers and conflicts from overhead video recordings, an in-vehicle eye tracker to investigate driver gaze patterns (number and duration glances) and gaze direction while traversing multilane roundabouts.

Instrumented vehicles, driven in either test-track or open-road environments, are capable of gathering detailed driver human factors and operational data. Vehicle instrumentation typically includes recording equipment to document driver movements and verbal responses that are precisely associated with vehicle performance characteristics. More sophisticated installations include eye-marker equipment, whereby driver eye movements and dwell time provide a definitive measure of driver detection. It is noteworthy that drive eye movements are subconscious occurrences, thereby producing results that are uncontaminated due to their collection in a research setting.

A good example of the variety of measures than can be found from an instrumented vehicle study was that of Stout, et al. (15) who developed prototype work zone devices (barriers, delineators and signs) and tested these on an unused airport runway to avoid safety and liability problems of using experimental traffic control devices on public highways. TCD effectiveness measures gathered via the instrumented vehicle were:

- <u>Device Recognition Time</u> - The elapsed time from the moment when a test device comes into the subject's field of view until the subject recognizes it as a device that may affect driving.
- <u>Device Interpretation Time</u> - The amount of time required for the subject to interpret an appropriate response to the device.
- <u>Interpretation Correctness</u> - Whether the subject responded correctly to the device.
- <u>Interpretation Issue-</u> Whether the subject misunderstood the message of the device.
- <u>Helpfulness Rating</u> - Categorical scale: Very helpful, Helpful, Not very helpful, Not at all helpful.
- <u>Safety Rating</u> - Categorical scale: Much safer, Somewhat safer, A little safer, No safer at all
- <u>Approach Speed</u> - Speed of the vehicle at the time that the device first came into the driver's view.
- <u>Device Arrival Speed</u>- Speed when the vehicle arrived at the device location.
- <u>Approach Speed Profile</u> - Difference between the above two speeds.
- <u>Device Approach Time</u> - Elapsed time between the approach and arrival speed measurements.
- <u>Speed Variance</u> - The mathematical variance function based upon a set of speed measurements taken between the approach and arrival speed points.

Sampling

An important issue in any evaluation is adequate sampling. The appropriate number and type of road users should be selected to participate in the study. It may be difficult to get a "representative" sample of road users, but the sample should include an appropriate mix of age and gender, especially including older divers or pedestrians and novice drivers. Good sources of test subjects include driver licensing offices, church groups, senior citizens centers and service clubs. However, many TCD studies have involved young University students, hardly a representative sample. As an incentive, participants may have to be paid an honorarium or a donation made to the relevant organization. In the study by Dewar, et al. (5) older drivers performed worse on all measures than did middle-aged or young drivers, confirming the importance of including seniors in the sample. And the driving population is ageing, so there will be more older drivers on the road.

Context

One's ability to detect and recognize a TCD is influenced in part by the context in which it is seen. The road environment frequently provides a clue as to the message on the TCD. If a sign or signal is not understood when first seen, its meaning may become evident to the driver after it is encountered a few times, or even once (e.g., a curve seen ahead on the road beyond a curve warning sign helps the driver understand the sign). Hence, it is wise to place a TCD in its proper context in a laboratory setting when testing how well drivers can detect, read and understand it. Context can be provided to the subject in different ways. It can be shown in a picture of the sign in a road scene, described to the subject (e.g., this sign appears on a road in advance of a steep hill, intersection, or steep mountain).

Criteria for performance

It is necessary to decide what proportion of road users must understand and respond correctly in a timely manner to a sign or signal configuration, for example, in order for it to be considered effective. Criterion levels of 65 percent correct comprehension have often been used, but even at 65 percent comprehension, more than one-third of people would not understand the meaning intended. The cut-off used to determine TCD effectiveness depends upon the importance of the message and the consequences of failing to detect or understand the message. One would use a more strict (higher level) cut-off for a NO LEFT TURN or DO NOT ENTER sign than for a CAMPGROUND or NO LITTERING sign, for example.

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Field Evaluation of Full-Matrix Color Changeable Message Signs

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INTRODUCTION

As technology and capabilities in Changeable Message Signs (CMSs) have evolved, traffic engineers are now able to install electronic signs with high resolution and can closely mimic static traffic signs. The MUTCD allows for the use of electronic signs; however, there remains a need to understand the types of messages, font styles, and backgrounds that are most effective to communicate information. The Federal Highway Administration (FHWA) through the Traffic Management Center (TMC) Pooled Fund Study (PFS) sponsored a project to develop recommendations for considerations related to the use of Color CMSs. This paper documents the field evaluation procedures and results portion of the project.

PURPOSE

The purpose of this evaluation was to determine road user understanding of and reaction to a variety of messages displayed on color, full-matrix Changeable Message Signs (CMSs). More specifically, the research team assessed the impacts that the signs have on motorists including:

- Do text and background colors influence legibility?
- Does font influence legibility?
- What are considerations for displaying CMS messages in daytime versus nighttime?
- What are participant preferences for various sign design features, and do these design features affect subjective ratings?
    - Are borders helpful on CMS messages?
    - Is there an optimal placement of symbols on CMS messages?
    - Does the use of color (i.e., color-coding) help to convey messages more easily?
- Does color influence participant feedback on sign brightness?

BACKGROUND

Chapter 2L of the Manual on Uniform Traffic Control Devices (MUTCD) (Federal Highway Administration, 2009) provides standards and guidance related to the use of CMSs. However, the MUTCD does not provide extensive guidance on the use of traffic control devices, rather it provides boundaries within which the device may be used. For some devices with a wide variety of uses, such as CMSs, additional guidelines are often necessary to further refine the best uses of these traffic control devices, as long as these guidelines fall within the Manual’s boundaries.
In light of this, there is a need for further research and guidelines to better assist transportation agencies who either use full-matrix CMS or are considering their use. The information included in guidelines must identify what messages are most effective, when to use them, and which format should be used (graphics versus text). The development of said guidelines and best practices requires an in-depth analysis by professionals who thoroughly understand effective traffic control device design, understand the development and application of research designs that will result in achieving useful results, and have experience working with practitioners to determine current practice and to ensure that the guidelines developed will be in a format useful to practitioners.

A limited number of guideline and policy documents have been developed that cover using color CMSs, both within the United States and internationally. Within the United States, the bulk of these documents were developed at the state level. International documents have been collected and reviewed from a number of countries, with the bulk from agencies within Europe and Australia. Most of the policies and guidelines do not incorporate the capabilities of more modern signs.

Dudek (2004) authored the *Changeable Message Sign Operation and Messaging Handbook* for FHWA. This document is similar to others Dudek authored at the state level (e.g., New Jersey, Texas). Although this document provides the reader with a significant amount of information on CMS operation and message design, there are few details about using colors, symbols, and graphics in the document because “until highway agencies can afford to install stadium and arena type full-matrix, full-color signs, use of graphics and symbols will be limited” (pg. 5-41). The only guidance on this topic within the document is to ensure that using graphics does not compromise the size of letters in the text message (Dudek, Changeable Message Sign Operation and Messaging Handbook, 2004).

Lichty et al. developed guidance for disseminating road weather advisory information for USDOT’s Research and Innovative Technology Administration in 2012. While this document did not focus on CMS, specific guidance was written in the document for displaying messages on CMSs. Specifically, the authors recommended using different colors on the CMS: green to communicate clear or normal; yellow to communicate caution, warning, slow moving areas of traffic; and red to communicate danger, emergencies, and extremely slow traffic. The authors also recommended using red lettering or background, as well as increasing the size of the symbols and, if possible, showing the consequences of not responding appropriately when communicating highly urgent messages (Lichty, Richard, Campbell, & Bacon, 2012).

While there has been much research into using color and symbols on CMSs, there have been few studies looking into message design, especially on full-matrix CMSs. Common practice in the United States is to include a single graphic on the left-hand side of the sign and the worded message on the right-hand side; however, the literature scan shows a mixture of different message design practices used successfully outside of the United States.

From the practitioner’s perspective, a major challenge in deploying and fully using color, full-matrix CMS signs is the lack of updated and detailed guidance. Many of the guidelines developed for CMSs, both on the state and Federal level, were developed in past years where this technology was rather new and the cost for the equipment was high. As color, full-matrix CMS equipment technology has matured and costs decreased, more agencies are purchasing these devices, but guidelines have not been updated or, in some cases, developed.

While some of these guidance documents are very detailed, many others simply provide general language stating that the symbols/graphics shall be in conformance with the MUTCD. New research in this area, coupled with highlighting existing best practices and developing a concise set of detailed guidelines for using colors and symbols on full-matrix CMSs will be beneficial to both those agencies looking to update their dated documents, as well as new agencies looking to develop new guidelines. Therefore, this evaluation aims to address some of these considerations.

METHOD

In order to address the research questions, the field study was organized into two parts. The first part investigated sign legibility using different fonts and different color combinations for the sign legend and background. The second part investigated participant preferences for different sign design elements.

Part 1 – Legibility

Ten different sign designs were developed for the legibility testing. These signs varied in legend color, background color, and font. Five background colors were tested (black, green, white, orange, and yellow) and five legend colors were tested (black, red, yellow, green, and white), though not every background color and legend color were tested together. Three different fonts were evaluated: Series D, Series E, and an LED-style font. Although the Series D and Series E styles cannot be exactly recreated on a CMS as they are on static signs, the high resolution of the CMS used for this study enabled the fonts to be displayed so they visually appear the same as those used on static signs. The LED-style font represented the font style that is traditionally used on CMSs. The three different fonts were evaluated on a single legend/background color combination; all other signs were developed using Series D font. Figure 1 shows the 10 sign designs that were developed for field legibility testing.

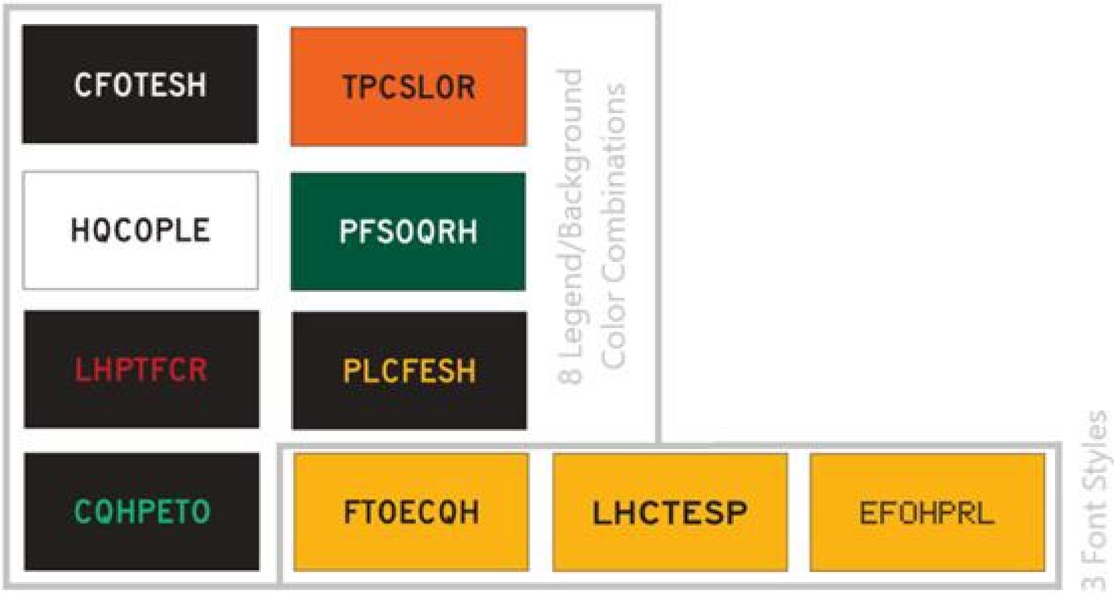

Figure 1. Example Signs Tested During the Field Study Part 1

The legend and background color combinations were selected to include both positive contrast (e.g., white text on black background, hereafter referred to as “white-on-black”) and negative contrast (e.g., black-on-white) signs. The white-on-green, yellow-on-black, black-on-yellow, and black-on-orange color combinations were included because these are common color combinations used on static signs and newer color CMS signs. Some participants in the laboratory study indicated that it was difficult to see red text on a black background, therefore, the red-on-black color combination was included in the field study in order to determine if there were similar findings when using a real CMS sign. The green-on-black color combination was included because this was the green included on the color-coded Travel Time and Toll Cost signs included in the laboratory study.

Each of the 10 sign designs displayed a string of seven uppercase letters. None of the messages formed a word in the English language, rather, they appeared as a random sequence of letters similar to an eye chart used for vision screening. The research team created three versions of each of the 10 signs, for a total of 30 signs. Each version of a sign included the same 7 letters that are shown on the signs in Figure 65, but presented in a different random order. For example, the white-on-black sign always included the letters C, F, O, T, E, S, and H, but versions one, two, and three of that sign had those seven letters presented in a different order. This was done to prevent participants from becoming familiar with the order in which letters were presented, thus reducing the chances that participants could recite letters by memory (rather than relying solely on reading the sign). The order of the signs displayed was developed to prevent participants from viewing signs with the same color and letter combination in succession. All participants viewed the signs in the same sequence.

Part 2 – Subjective Feedback

The second part of the field test gathered participant preference for different sign design elements including messaging with color (i.e., color-coding), border presence, and symbol placement. This entailed the participants viewing seven groups of signs. Six of these seven sign groups investigated participant preferences for different sign designs within each group of signs. Two groups of signs were used to test each of the three sign design elements of interest (symbol placement, border presence, and color-coding). The sign messages and testing goals are shown in Table 1.

Table 1. Signs Tested During the Field Study Part 2

Sign Message and Testing Goal	Sign Design		Sign Message and Testing Goal	Sign Design
ROAD WORK AHEAD Investigate participant preference for a sign border	 		RAMP CLOSED TO I-95 NORTH Investigate participant preference for the inclusion and placement of a symbol.	  
RAMP CLOSED TO I-95 NORTH Investigate participant preference for a sign border	 		TRAVEL TIME Investigate participant preference for a legend with multiple colors.	 
NO TRUCKS Investigate participant preference for the inclusion and placement of a symbol.	  		TOLL COST Investigate participant preference for a legend with multiple colors.	 

The seventh group of signs all had the same message: ROAD CLOSED AHEAD (Figure 2). This group of signs varied in background color (black, white, and yellow) as well as legend color (white, red, and black). During this part of the study, experimenters showed participants one sign at a time and asked participants to provide feedback on each sign's brightness level (e.g., sign is too bright, sign is too dim). Each sign was shown at the sign's brightest level, which was the sign's default setting.

Figure 2. Signs Studied for Brightness

Apparatus

The CMS used for this experiment was a 4 foot by 8-foot high-resolution, full color sign. The CMS had a pixel pitch of 4 millimeters, a pixel density of 62,500 pixels per square meter, and a cabinet resolution of 640 x 320 pixels. The research team mounted the sign to the side of a trailer for portability. The CMS set-up is shown in Figure 3.

Figure 3. Photo. Experimenter and Participant during the Field Test Part 2

Participants

A total of 27 people participated in the field study, though only 26 participants produced usable data; one participant arrived late and was unable to provide responses to many of the questions, so was excluded from the data analysis. Of the 26 participants with usable data, 15 completed the study during the day and 11 completed the study at night. Participants ranged from 19-67 years old with an average age of 43 years. Forty-one percent (41%) of the participants were male (average age 53 years) and 59% were female (average age 37 years). Participants were required to be at least 18 years of age in order to participate. Their vision was scored using a Snellen Eye Chart. All participants had at least 20/40 vision in one or both eyes, corrected if necessary.

Participants were primarily recruited through an online advertisement placed on Craigslist, as well as by word-of-mouth. The advertisement provided general information about the study with a link to an online form that people could complete to submit their interest to the research team. The experiment was reviewed and approved by an Institutional Review Board (IRB).

Field Data Collection

The field study was conducted in Blacksburg, Virginia on an access road that was closed to normal traffic and provided a controlled environment where participants could not be distracted by other traffic. The access road was approximately 2000 feet long, and the section of road used as the test road for the study was approximately 800’ in length with a small vertical curve and no horizontal curves. This configuration gave participants an unobstructed view of the CMS throughout the entire duration of the study.

Field data was collected between 7:30 a.m. ET and 9:30 p.m. ET each in order to analyze legibility in both daytime and nighttime conditions. As mentioned previously, a light meter was used to measure the amount of ambient lighting at the time that each participant started the study.

The participants did not drive the research vehicle; the experimenter and participant were only seated in the front seat of the research vehicle in order to view the signs and stay out of the cold. The experimenter administered a vision screening using a Snellen Eye Chart mounted inside the CMS trailer. Participants were asked to stand at a marked location that was 10’ from the eye chart and asked to read the lowest line they could easily see. Participants’ vision scores were recorded on a form. All participants had at least 20/40 vision in one or both eyes, corrected if necessary.

After the vision screening, the experimenter used the light meter to establish the amount of ambient lighting. The measurement was recorded on the vision screening form. The experimenter would then power on the sign and drive the participant to the furthest marked distance from the sign, which was 900’.

Once the experimenter and participants were situated at the farthest marked distance from the sign, the sign program began, and the participants viewed each of the ten signs shown in Figure 1. Participants viewed one sign at a time and were instructed to read the letters on the sign aloud, as they could see them, similar to what they might do for an eye chart. The experimenter recorded the letters read by the participants into a spreadsheet on a laptop computer. The experimenter advised participants to let him/her know if they could not see a letter or to let the experimenter know if they thought they could see a letter but were partially guessing. If participants were undecided between two letters (e.g., O or Q), the experimenter would ask them to make their best decision. After responding to the first sign, the participants repeated that process for all 10 signs.

After viewing all 10 signs at the farthest distance, the experimenter and participants moved to the next closest distance from the sign and repeated the same process of viewing all 10 signs. This process occurred at six different pre-determined distances from the sign: 900 feet, 750 feet, 600 feet, 525 feet, 450 feet, and 300 feet.[1] The order of the letters on the signs, and the order of the signs within a group were randomized and differed at each distance.

After the participants concluded the legibility testing at all six distances (Part 1), the experimenter and participants remained at the 300-foot distance for Part 2 of the field study. The second part of the field study consisted of showing participants seven different sets of signs and asking for their subjective feedback and preference for different sign designs within a given group of signs. The 300-foot distance was selected because it was a comfortable viewing distance from which the sign would be clearly legible to participants.

During this part of the testing, participants were asked questions about the signs in order to determine preferences for design elements. Participant preferences were measured for the following sign elements: border presence, symbol presence, symbol placement, color coding, and sign brightness. Each set of signs included at least two different sign designs that incorporated one of the sign elements being tested in different ways. The participants viewed each sign within a sign group twice and then the experimenter would ask the participants if they noticed any differences between the signs. The experimenter recorded participant responses on a laptop computer. Next, the experimenter told the participants the intended meaning of the current signs they were viewing and asked the participants to rate each sign alternative within that sign group. The participants saw each sign again and rated each one on a scale of 1 (would not work at all) to 5 (would work very well) to indicate how well they thought the sign conveyed the intended meaning.

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[1] The distances were initially set to 900’, 750’, 600’, 450’, 300’ and 150’ but, based on an initial analysis of data, the research team decided to remove the 150’ distance due to the high level of accuracy achieved at the 300’ distance, and add the 525’ distance due to the large disparity in accuracy between the 600’ and 450’ distances.

After recording the participant's ratings, the experimenter asked participants if they preferred one sign design over the other(s), or if they had any additional feedback that they wanted to provide about the signs they just viewed. The research recorded any feedback or information that the participants provided. This process was repeated for each of the six sign groups described in Table 1. The seventh set of signs (Figure 2) was used to gauge participants' reactions to brightness levels. During this part of the study, participants saw the Road Closed Ahead sign in four different text and background color combinations. Each time a sign appeared, the participants were asked for their feedback on the brightness level (i.e., if the sign was too bright or too dim). The experimenter recorded the participants' feedback on each sign's brightness level, and this concluded their participation in the study.

RESULTS

For the legibility testing, participants were shown a sign at each of the six marked distances and asked to read the letters out loud. These were then compared against the actual letters to calculate a score for each trial ranging from 0% (0 of 7 letters correctly identified) to 100% (all 7 letters correctly identified). The maximum distance at which each participant could correctly identify all letters was found and used as the dependent variable in statistical models. There were 11 cases in which participants could not do so at any distance; these cases were assigned a legibility distance value of 0 feet. Mixed effects linear models were fit to allow for fixed effects of light (daytime vs. nighttime) and colors (and their interaction), and random effects of vision and participant-specific intercepts. Various response distributions were assessed, but the Normal always performed best. The results of the field testing are organized by the findings related to each of the field study research questions.

Do legend and background colors influence legibility?

Figure 4 shows the mean accuracy for each sign at each distance. The black-on-orange color combination garnered the longest average legibility distance (484 ft) and was statistically significantly greater than that of all other signs with the exception of black-on-yellow and white-on-black. The shortest legibility distance was observed for green-on-black (262 ft), which was not statistically different from white-on-green (290 ft).

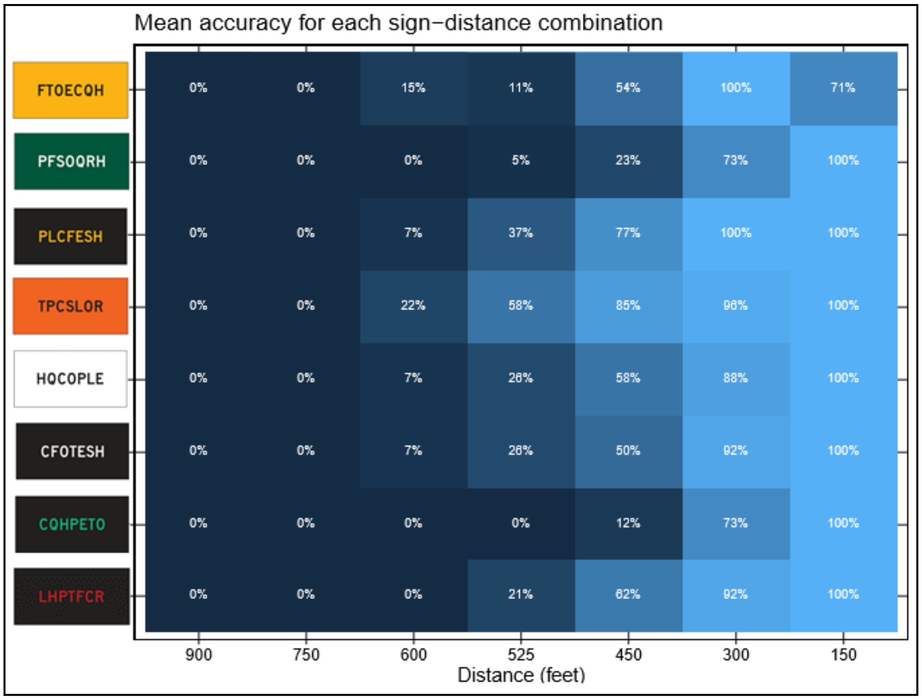

Figure 4. Mean accuracy for each sign alternative at each distance. The percentages represent the percentage of participants who were fully correct (i.e., correctly identified each letter on the sign).

The CMS used for the field testing was a 4 foot by 8-foot sign, and therefore font size was scaled to 10.4-inch letters in order to fit properly on the signs. The overall effect of light (daytime vs. nighttime) was insignificant ($p > 0.05$), but the legibility of one-color combination was affected. For yellow-on-black, daytime legibility averaged 495 feet versus 392 feet at night (difference = 103 feet, $p < 0.05$).

Does font influence legibility?

Series E garnered the longest legibility distance (509 ft), which was statistically significantly greater than the distance associated with Series D (406 ft, difference = 103 ft, $p<0.01$) and LED (439 ft, difference = 69 ft, $p<0.01$). The effect of light was not statistically significant.

Do various design features affect subjective ratings?

Participants were shown six different sign categories, each with 2-3 sign alternatives (as shown in Table 1). Each sign category was used to investigate one of three design features: border presence, the use of color-coding, and symbol placement. Participants rated each stimulus from 1 (would not work at all) to 5 (would work very well). Similar mixed effects statistical models were estimated here, using the numeric rating as the dependent variable. Participants were also given an opportunity to provide open-ended feedback on each sign category, including preference for different sign designs or any other feedback they wished to provide.

Border Presence - “Road Work Ahead” and “Ramp Closed” signs included alternatives with and without borders. The border alternative garnered higher subjective ratings of the Road Work Ahead signs (mean without border = 3.9, mean with border = 4.5, difference = 0.6, $p < 0.01$). The Ramp Closed sign ratings were not affected by the presence of a border.

The Road Work Ahead sign was used as an example where there was less text and more space between the legend and the horizontal edges of the sign, whereas the Ramp Closed sign was used as an example where there was very little background space remaining between the text and the horizontal edges of the sign. Although the average ratings for the sign with a border were similar for Road Work Ahead (4.53) and for Ramp Closed (4.47), the ratings for the signs without borders were slightly higher for Ramp Closed (4.22) than they were for Road Work Ahead (3.91). Additionally, 70% of participants indicated that they preferred the Road Work Ahead sign with the border, compared to 56% who indicated that they preferred the Ramp Closed sign with the border (even though more participants noticed the border on the Ramp Closed signs than they did on the Road Work Ahead signs). These findings could be an indication that participants may gravitate toward a border particularly when there is excess free space on a sign, however, further research would be required to examine this. The laboratory study findings did not indicate that participant ratings were influences by border presence, but rather were influenced by symbol use/placement or text/background color. The effect of light was insignificant for both signs.

Color Coding - "Travel Time" and "Toll Cost" signs included alternatives with yellow text and multi-colored text. The yellow-only alternative garnered higher subjective ratings of the Travel Time signs (mean with yellow text = 4.2, mean with multi-colored text = 3.6, difference = 0.6, $p < 0.05$). However, this difference only appears among the daytime participants (difference = 0.9, $p < 0.05$; at night: difference = 0.4, $p > 0.05$). The Toll Cost sign ratings were not affected by text color or light ($p>0.05$).

Although participants in the laboratory were not asked their preference for the Travel Time or Toll Cost signs, they were asked what they thought the colors (i.e., color-coding) were trying to tell them. For the Toll Cost signs, about 54% of participant responses indicated a general understanding of the intended meaning of the color-coding (indicating amount of traffic and/or cost relative to normal). For the Travel Time signs, about 71% indicated a general understanding of the intended meaning (indicating amount of traffic and/or travel times relative to normal times). With participant preference for Toll Cost and Travel Time signs at 52% and 56%, respectively, and participant understanding of the meaning behind the color-coding (54% and 71%, respectively), it is possible that preference for signs (yellow-only vs. color-coded) could be influenced by their understanding of the color-coding.

Symbol Placement - "Ramp Closed" and "No Trucks" signs included alternatives with three different symbol placement options. The presence of a symbol (whether placed in the center or on the left) garnered higher subjective ratings of the Road Closed signs (mean without symbol = 3.2, mean with symbol in center = 4.1, mean with symbol on left = 4.5; difference between no symbol and center = 0.9, $p<0.01$; difference between no symbol and left = 1.3, $p<0.01$; difference between center and left = 0.4, $p>0.05$). Center-placement (symbol-only) garnered lower ratings of the No Trucks alternatives (mean symbol in center = 3.0, mean with symbol on left = 4.2, mean with symbol on right = 4.5; difference between center and left = 1.2, $p<0.01$; difference between center and right = 1.5, $p<0.01$; difference between left and right = 0.2, $p>0.05$). The effect of light was insignificant for both signs.

For the No Trucks sign group, participants were asked if they had any preference for certain signs over the others. Eighty-two percent (82%) of participants preferred a sign with both the symbol and the text, as opposed to the symbol-only sign. Approximately 42% of participants specified that they particularly prefer the symbol to the right of the text, whereas 19% specified that they prefer the symbol to the left of the text. The findings are similar to the laboratory findings regarding No Trucks signs. Participants rated the signs with both symbols and text higher than the symbol-only signs.

Participants were also asked to indicate if they had any preference for certain signs in the Ramp Closed sign group. Thirty-five percent (35%) of participants indicated that they prefer the sign with the route shield to the left of the text, 31% preferred the sign with the route shield within the text, 15% preferred either sign that included a route shield, 15% preferred the sign with text only, and 4% had no preference. The participants (35%) who preferred the route shield to the left of the text liked that this sign had both the symbol (route shield) and the test. They also tended to like that the route shield was larger on this sign, which they reported was helpful if you are looking for I-95, and also helpful if you are not looking for I-95 because you would see the route shield first, know that the sign doesn't apply to you, and thus not have to read the rest of the sign. The participants (31%) who preferred the sign with the route shield within the text liked that this sign had both text and symbol (route shield), but generally thought that this sign "flowed" the best. They liked that it included both the symbol (route shield) and the text but indicated that it seemed less crowded than the sign with the route shield to the left of the text. Participants liked that this sign could be read like a sentence and was more intuitive than the sign with the route shield on the left because in that scenario they have to connect what the symbol and words are saying. They also felt like the sign with the route shield within in text didn't feel as cramped as the sign with the route shield to the left of the text. The participants (15%) who preferred the sign with only text indicated that this sign was simple and easiest to read. These findings were similar to the Ramp Closed findings from the laboratory study. Although reaction times were slightly higher than average for the symbol-center and slightly lower than average for the symbol-right, the rankings indicated that participants preferred either sign that included the symbol with the text over the sign than included text-only.

In general, the laboratory and field study findings regarding symbol placement are similar in that participants prefer signs that include both symbols and text more than text-only signs or symbol-only signs.

Participant Feedback on Sign Brightness for Different Legend and Background Colors

Participants were shown four different legend/background color combinations for a Road Closed Ahead sign and provided feedback on the brightness of each sign. Participant responses were coded into one of three categories based on the feedback they provided about the sign brightness: "too bright" (+1), "good level of brightness" (0), and "too dim" (-1).

A mixed effects linear model was fit to allow for fixed effects of light and colors (and their interaction), and random effects of vision and participant-specific intercepts. The findings indicated that text/background color combination influences how bright participants feel a sign is. The black-on-white sign alternative was rated as the brightest color combination (mean rating = 0.64, 95% CI: 0.45, 0.83), while the red-on-black was rated as the dimmest (mean rating = -0.28, 95% CI: -0.48, -0.07). Black-on-white was rated as significantly brighter than all other combinations ($p < 0.05$). Red-on-black was rated as significantly dimmer than black-on-white (difference = 0.9, $p < 0.01$) and black-on-yellow (difference = 0.5, $p < 0.01$), but not white-on-black (difference = 0.3, $p > 0.05$). Black-on-yellow and white-on-black were not statistically significantly different from one another ($p > 0.5$).

An analysis was conducted to determine if perception of brightness for each sign varied by time of day (daytime vs. nighttime). Overall, the signs rated during the night were rated as brighter than those rated during the day (difference = 0.3, $p < 0.01$). However, the statistical significance of this difference disappears when examining each sign individually ($p > 0.05$).

CONCLUSIONS AND RECOMMENDATIONS

Symbol Use and Placement -

Participant subjective ratings indicated that signs with both text and symbols (with the symbols presented either to the left or right of the text) are preferred over other sign alternatives across all sign categories that were tested with symbols. Further research would be required to determine if sign comprehension is influenced by symbols for different sign messages other than the seven sign messages that included symbols in this study. For example, research on other sign messages not included in this study may indicate that sign messages that are not as comprehensible could benefit from the use of a symbol (e.g., to benefit non-native English speakers).

Use of Color -

The field study indicated that the black-on-orange signs resulted in the longest average legibility distance and was significantly greater than all other signs except for the white-on-black and black-on-yellow signs. The field study also indicated the shortest legibility for green-on-black signs, followed by white-on-green signs. The field study yielded no statistically significant differences between the white-on-black, yellow-on-black, black-on-white, and black-on-yellow signs.

When examining the concept of color-coding, participant field ratings of the Travel Time and Toll Cost signs garnered higher ratings for the yellow-only (not color-coded) alternatives for Travel Time signs (for daytime participants only), with no difference for Toll Cost signs. For both the Travel Time and Toll Cost categories, more participants (52% and 56%, respectively) furthered mentioned that they preferred the yellow-only signs than those who mentioned they preferred the color-coded sign (26% and 30%, respectively), with 19% (in both sign categories) indicating no preference.

Use of Borders -

In the field study, participant subjective ratings for the Road Work Ahead signs were significantly higher for the sign with the border than the sign without the border. And, although more participants noticed the border for the Ramp Closed signs than they did on the Road Work Ahead signs, fewer participants mentioned that they prefer the sign with the border for the Ramp Closed signs than for the Road Work Ahead signs. These findings could be due to the amount of text that is included on the signs. The Ramp Closed sign has more text that extends to the edge of the border, whereas the Road Work Ahead sign includes more free space between the text and the edge of the border. However, the signs were also presented in different text/background color combinations. Additional research, focused on the presence of borders, would be required to better understand why borders might improve legibility and to further examine the effects of background color and amount of text on preference for borders.

Considerations for Use of CMS in Daytime versus Nighttime -
Legibility distances in the field study did not vary significantly in the daytime versus nighttime, except for yellow-on-black signs. For these signs, legibility distance was significantly longer during the daytime than at nighttime. Participant subjective ratings of signs with varying design features (border presence, color-coding, symbol placement) were not affected by light (daytime vs. nighttime), except for the Travel Time signs. For these signs, participants rated the yellow-only signs significantly higher than the signs with multi-colored text, but only during the daytime.

Participants were shown four different legend/background color combinations (black-on-white, black-on-yellow, red-on-black, white-on-black) for a text-only sign and provided feedback on the brightness of each sign. Overall, the signs rated during the night were rated as brighter than those rated during the day. However, the statistical significance of this difference disappears when examining each sign individually.

Font Style -
The findings indicated that Series E had the longest average legibility distance, which was significantly longer than Series D and the LED-style font. This is not a surprising finding, as Series E has wider letters and was designed to be seen further than Series D, even on static signs. A more comprehensive font study could also examine the effects of mimicking signs using mixed-case on CMSs.

Limitations and Future Research -
A limitation of the current study is that font style was only evaluated using one text/background color combination. This preliminary look into font on CMSs showed that different font styles may be more effective than others on full matrix color CMSs, however, a more comprehensive study looking at legibility of various fonts would be useful. A secondary study could evaluate fonts using various text and background color combinations. Additionally, although the current study included a preliminary evaluation of the effects of color on perception of sign brightness, a study focused specifically on brightness and lighting could evaluate optimal levels of brightness under varying lighting conditions. Additionally, due to the design of the current field study, the CMS (which was mounted to a trailer) essentially resembled a ground-mounted sign. The current study did not evaluate what the impacts would be if the sign was overhead.

Additional research would be needed to determine which symbols are highly recognizable to motorists and which are not. Though some research has been conducted on symbol signs using static signs, additional research would be required, followed by deployment and use, to determine what factors make a symbol highly recognizable to motorists.

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STOP

ABOUT THE IMAGERY

Photos exhibited apart from the research papers in this publication are intended to highlight useful, innovative, unusual, unique, archaic, or even nostalgic traffic control devices. A description of the photos in order is provided below.

> *A rather riveting example of motorway services signing in western Montana features demountable aluminum legend, a technology long since replaced by electrostatic-cling film and state-of-the-art deposition systems.*
>
> *Spread it on thick, like the humidity in the air around this parking lot arrow in the mid-South, which apparently has quite the track record.*
>
> *Incandescent bulbs will stop you in your tracks at a signalized intersection in Paris, Tennessee, featuring text-based displays for pedestrian signals.*
>
> *A roller-coaster ride of flyover ramps and braided ramps in Florida provides for easy access to Interstate 4 from nearby attractions.*
>
> *European motorway operators have handily demonstrated there is no wrong way to make it obvious that it's time to stop and turn around.*
>
> *Nothing says "punch it" quite like an embossed R1-1 and this example in northwest Indiana is ready to end up behind glass instead of wire fabric.*
>
> *Not all who wander are lost but few will wander too far in rural Mississippi thanks to these dotted extension markings coupled with raised reflective pavement markers and diagonal markings in the flush median.*

All photos outside of the research papers in this edition are courtesy of Scott O. Kuznicki, from a personal collection of 1.5 million photos and videos spanning 25 years of travel in countries around the globe. Visit transportationpixels.com to learn more about how this collection and others like it will be launched in an crowd-sourced format featuring billions of photographs, for the benefit of practitioners and researchers.

Photograph submissions for future issues of the Journal may be made directly to the editors or by addressing @scottokuznicki on social media.

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