Traffic Control Devices Pooled Fund Study

Traffic Control Devices at Transponder-Controlled Tollbooth Lanes

Final Report

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

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

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- Visit www.pooledfund.org and search for study # TPF-5(065).

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EXECUTIVE SUMMARY

Currently, the number of toll roads are increasing in the United States and the signing practices that do exist vary across jurisdictions. In addition to the expansion in toll roads, there is an increase in the use of electronic toll collection (ETC) transponders. While some standardization is evident, especially on the E-ZPass-supported toll facilities, toll road signage, guidance information, and the designs for the pictographs used for the toll road names (e.g., E-ZPass, I-Pass, etc.) reflect a variety of graphical conventions.

To address four basic elements of ETC-supported toll road signs (background color, font color, underlay color, and pictograph) this study was conducted.

The study reviewed selected ETC toll road signs in the United States to help determine basic elements and options to be used in the laboratory experiment. Based on this information, 35mm slides were developed using a standard sign-design software package. The 120 signs used the following elements in various combinations:

- Six background colors - black, green, white, yellow, light blue and purple
- Four font colors – black, green, white, and yellow
- Five colors that underlay the toll road pictograph – black, green, white, yellow, and light blue
- Four pictographs currently in use – EZ TAG, E-ZPass, I-Pass, and FasTrak

The signs were presented to 60 subjects (equally divided by sex and age group) in the Turner-Fairbank Highway Research Center's Sign Simulator. The signs were shown to subjects starting at a simulated distance of approximately 13,500 feet and would "zoom" toward the subjects, at a constant speed controlled by the laboratory's computer. Subjects indicated when they could first see the sign (detection distance); when they could read the guidance information

(guidance legibility distance) and when they could read the pictograph (pictograph legibility distance).

Analysis of the results showed that

- Overall, green as a background color obtained the longest guidance information legibility distance
- Fonts that provided the highest contrast to the background color (such as white) were most effective for legibility
- The EZ TAG pictograph (which was purple, as were all pictographs in this study) showed dramatically longer legibility distances than did the other pictographs, this result was consistent across all underlay colors
- The underlay colors that showed the highest contrast to the pictographs were most effective and included all the lighter colors tested (white, yellow, and light blue)

Based on these results, the following recommendations are offered (assuming the pictographs remain purple, as tested in this study):

- Green is the established guidance sign color. Its effectiveness in this study shows it should be retained and the font color should remain white.
- Purple as "the" pictograph color appears to be a good choice but only if its underlay is a highly contrasting color such as white or green or even light blue.
- This study shows there is some evidence that "more stylized" pictographs can be difficult to read, especially at farther distances and for drivers who may be new to the toll facility. It is recommended that to help drivers read these, the type of design be carefully considered, especially to allow a high underlay to pictograph ratio or to simplify the new pictographs, when possible.
- Finally, the research supports other research showing older drivers need more time to perceive and process information. This information should be considered for guidelines on sign placement and frequency along toll roads.

1. INTRODUCTION

Bob is traveling from Boston to Florida, driving on interstates, back roads, and occasionally, toll roads. As he drives South, he marvels at how easy it is to follow the Interstate, State, and County roads. The sign shapes, colors, and numbering schemes are all consistent between the States, counties, and towns. It seems impossible to get lost – until he decides to drive on the toll roads.

The first two toll roads seem relatively easy, the New Jersey Turnpike and the New York State Thruway. Since he has an E-ZPass, he recognizes the Electronic Toll Collection (ETC) lanes and uses them accordingly. After driving on some back roads to get soft shell crab near the Chesapeake Bay, he returns to the Interstate and then the Dulles Toll Road. Seems like a bargain to get through Northern Virginia near rush hour but he asks himself, "What is SmartTag? – Is that like E-ZPass?" "Why is the sign a pinkish red?" Not taking a chance of trying to use his E-ZPass in what looks like an (ETC) lane, he drives through the exact change lane to pay his toll, even though he might also be charged on his E-ZPass account. Staying on I-95 through the mid-Atlantic, he decides to stop in South Carolina to see a friend in Hilton Head. Rather than try to use the local roads, he sees a yellow sign warning him of a toll road ahead. As he merges on, he spies what looks like a stylized letter "P" ("… or is it a Palm tree?"…) and a sign with, "Palmetto Pass," written on it. Is this road only for the locals?" he wonders. He continues on and finally reaches his friend's house in Florida.

Bob's questions and concerns about toll roads and ETC lanes are not unique. Thanks to the MUTCD, virtually all roads in the United States have a standardized and consistent system to guide drivers throughout the entire country. Their shapes, colors, and placement – basically all sign elements and parameters – have been carefully researched. Their operational and installation requirements are specified in the MUTCD; except for signs that are used on toll roads.

2. BACKGROUND

As discussed above, the number of toll lanes and toll roads being developed is increasing and is expected to increase even more in the next decade (U.S. Department of Transportation, Joint Program Office, 2003).

This issue is becoming more important due to a recent increase in the design, construction, and operation of toll roads within the United States. In addition, new federal legislation has continued this trend by authorizing states to convert existing freeways to toll ways (Public Law 105-178, United States of America, 1998.

A recent Washington Post column (2003) reflected on this issue when the newspaper published a letter from a Northern Virginia commuter who wrote:

> "On the Dulles Toll Road, all the tollbooth signs use black print on white backgrounds, often with small typefaces. As a result, many drivers cannot distinguish between attended, exact change and Smart Tag lanes. Almost every day, I see confused drivers who are either stopped in the wrong lanes or who make dangerous last-second lane changes to correct their mistakes. "

This driver's comments show how negotiating toll roads has become more complex and how much more difficult toll road driving can become, especially with the increase in the number of toll road authorities that are developing and offering an electronic toll collection (ETC) payment method. Already 18 states have deployed ETC, supporting 3,505 toll lanes (U.S. Department of Transportation, 2003.) While those ETC toll lanes show significant increases in traffic flow, the increase in ETC has led to more confusion at tollbooths and plazas since different payment options have become available to drivers. These typically are; 1) Exact change, 2) Full Service, and 3) Transponder-equipped vehicles only. Inadequate or inconsistent signing can lead to an increase in driver confusion and maneuver errors. Drivers have been observed trying to identify which lanes (sometimes from a total of twelve) are ETC lanes, exact change or full service lanes, (Chao, 2002). The information processing demands at the toll plazas, coupled with variable driving speeds and frequent lane changing, highlights the need to improve signing on toll roads.

Some states, such as those in the Northeastern corridor, are providing systems such as E-ZPass, that offer an inter-state, integrated payment option for tolls. This system allows drivers to travel on major freeways with a single transponder that works on all toll systems in each of the cooperating states. While a standardized toll road *payment* system is a boon to travelers, there is no standardized toll road *signing* system across the United States.

The E-ZPass signs are relatively consistent in the different states where they are in operation. With slight variations, the pictograph's color and font have become relatively standardized in the states that support this system. However, this situation is not universal; a number of neighboring states that offer ETC (including those with E-ZPass) have signs that are distinctly different from each other and reflect inconsistent applications. These practices can lead local drivers, who may have become accustomed to their "native toll way" sign and pictograph to become confused when traveling to another state, when they are faced with a new sign and/or pictograph for a different toll payment system. Adding to the confusion is the uncertainty whether a neighboring state's ETC lanes accept the driver's transponder as payment.

It is important to remember that guidance and advisory signing relies on a <u>total system</u> approach that includes a number of highway elements such as pavement markings and in addition to signing. Furthermore, all elements are designed to complement each other to help drivers. While the Center for Applied Research, Inc. is cognizant of the goal for system comprehensiveness, this project's focus is an initial attempt to identify current practices at toll roads for transponder-equipped lanes and identify basic characteristics of <u>signing</u> practices. This study will result in a set of basic <u>signing</u> recommendations that can be consistently applied to toll roads that use ETC. This information can also be used to help develop design guidelines for additional elements of toll roads, such as pavement markings, variable message signs, and even radio broadcasts to provide a consistent and comprehensive set of positive guidance information sources well in advance of a toll plaza. Results of this research could be used to provide traffic engineers with parameters such as the most effective distances and message content that need to be conveyed to drivers. By integrating information from the various design elements, drivers could receive information from a number of different media so they can plan correct lane placement as they near the toll plaza.

3. PROJECT RATIONALE AND OBJECTIVE

The objective of the project was to develop a set of basic signing recommendations to be used by toll road designers and engineers to assist drivers in identifying those toll lanes that are designed for transponder-equipped or electronic toll collection (ETC) vehicles. The recommendations are based on an evaluation process that addressed the following sign characteristics:

- Background color
- Font color
- Overlay color in combination with pictographs displaying various toll road sign names used at existing toll facilities.

The following sections describe and discuss the procedures and methods used to conduct the experiments and the results obtained.

4. METHODOLOGY

This section will present the procedures and protocols developed to conduct the field observation task as well as the laboratory experiment.

Overview of Process

The project's focus was on the laboratory experiment, which was conducted to help assess which sign element colors (background, font, pictograph, and underlay) were effective in terms of detection and guidance legibility.

Field Study/Review

In order to help determine which sign parameters would be included in the laboratory experiment, information was gathered from a number of toll roads and toll authorities in the United States. The toll roads chosen for the study included the following:

- Garden State Parkway
- New Jersey Turnpike
- Dulles Airport Toll Road
- Dulles Greenway Toll Road
- Harris County (Texas) Toll Road
- Hilton Head Island Tollway
- New York Thruway
- West Virginia Turnpike

Toll road representatives were contacted and asked to supply information regarding the current signing practices on the roads. Information was gathered from phone interviews, web searches, and materials received from toll road representatives. Sample signs (examples are included in Appendix A) as well as descriptions of the toll roads, drawings of the signs and their placement, as well as operational information were gathered.

The collected information yielded a number of general findings that were considered for inclusion as parameters in the laboratory experiments. These included::

- The toll road signs to be simulated would be based on an approach sign measuring ten by sixteen feet
- Letter height was set at twelve inches, which exceeds the MUTCD's minimum recommendation of ten inch letters for guidance information.
- The approach speed for the simulation would be programmed at 35 miles per hour
- The pictographs represented on the signs were FasTrak, E-ZPass, I-Pass, and EZ-TAG

Sign Stimuli

The sign stimuli used for the experiment consisted of 35mm slides, presented to subjects with a zoom lens in the Sign Simulator (a description follows in the next section). The sign parameters and design were based on the field review information (above) as well as a review of current toll road operations and discussions with the Pooled Fund Members.

Colors. Discussions regarding sign background color, font color, pictograph color and the color used under the logo (the underlay) were undertaken to determine those colors most likely to be implemented by states, those that are still "free," and other factors.

Background Color. The MUTCD currently designates white, green, and yellow for informational, guidance and warning signs, respectively. Three "free" colors are available for other signs; light blue, coral, and purple. A number of states have reported using fluorescent pink signs for incident management and traffic warnings.

The following six colors were selected as appropriate for this study:

- Black
- White

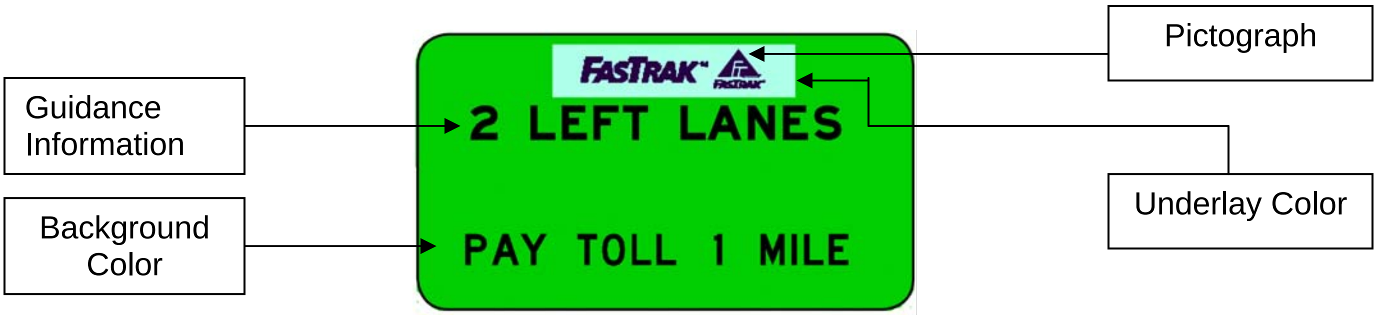
- Yellow
- Green
- Light Blue
- Purple

Font Color and Type. Again, discussions with the Pooled Fund Members and the study team were conducted to downselect the font types and colors that would be implementable. Using current recommendations from the MUTCD as well as toll road practices, it was determined that the following four colors would be included in the laboratory experiment:

- Black
- While
- Yellow
- Green

The following discussion relates to the elements highlighted in the sample sign below.

Figure 1. Example Laboratory Experiment Sign



Pictograph and Pictograph Color. As discussed in the introduction of this report, E-ZPass use constitutes the majority of ETC lane operations and vehicle transactions in the country. E-ZPass systems are operational in New York, New Jersey, Pennsylvania, Maryland, Delaware, Massachusetts, and West Virginia; its use represents fully 35% of all ETC-supported toll lanes in the United States. Similarly, this system (and color) is supported by approximately 40% of the agencies that oversee ETC-supported lanes. In addition, as new toll roads have opened in the Eastern United States, they have built E-ZPass inter-operability into their systems. They have also adopted the E-ZPass pictograph and color for their toll road signage. Since it appears that E-ZPass' sign characteristics define the pictograph standard, it was decided the color purple would be the only color for the pictograph. In addition, for purposes of the experiment, toll road pictographs comprised of random letters were also included. These "nonsense" toll road pictographs were used in the experiment to help validate subjects' recognition and comprehension of the pictographs. By including "nonsense" letters, though roughly designed like the real pictographs, it helped to keep subjects from just guessing which pictograph they were viewing from a distance.

Underlay Color. Toll roads use different colors for the layer underneath the pictograph. For this experiment, this was termed the "underlay." As with the background sign parameters, it was decided that all background sign colors should also be used for the underlay.

Table 1 presents the combination of the colors of each of the sign elements tested in the study. The 5 underlay colors used for each Background Color are listed in the Background Color rows.

Table 1. Sign Stimuli Color Parameters – Background, Font, and Underlay

Background Color	Font Color			
	White	Black	Yellow	Green
White	Black, Green, Yellow, Blue, Purple			
Black	White, Green, Yellow, Blue, Purple			
Green	Black, White, Yellow, Blue, Purple			
Yellow	Black, Green, White, Blue, Purple			
Blue	Black, Green, Yellow, White, Purple			
Purple	Black, Green, Yellow, Blue, White			

As shown, there were 6 background colors, 4 font colors, and 5 underlay colors. The combination of all factors resulted in 120 signs representing all combinations. All combinations were used in the experiment, including, those combinations where the font was identical to the background color, for example, the black font on black background. Essentially, this condition resulted in a sign with a blank lane assignment field – this was done, as with the random toll road names, to help provide a validity check on subjects' guessing of the guidance information, especially for those signs with font and background colors with low contrast, such as a yellow font on a white background.

Guidance Information. In addition to the pictographs, the sign included informational and lane assignment information to guide drivers to the correct ETC lanes. All signs included the message "Toll Plaza 1 Mile" or "Pay Toll 1 Mile." In addition, the signs included one of four lane assignment messages that were randomized across the 120 signs and included:

- 2 Left Lanes
- 2 Right Lanes
- Left Lane
- Right Lane

Sign Production. The slides were created using SignCADD, a Sign-building application, typically used by highway engineers to design signs for state departments of transportation. The font was FHWA Series D and the colors were also standard FHWA approved colors.

All signs were produced digitally and converted to 35mm slides for use in the SignSimulator. Representative examples are displayed in Appendix B.

Subjects

A total of 60 subjects participated in the experiment and the group was equally divided by sex. Subjects ranged in age from 19 to 89 and were grouped into two equal age groups – Younger (under 60) and Older (60 and over). This resulted in 15 subjects in each age group/sex combination. The subjects were volunteers recruited from the subject pool list maintained by the Human Centered Systems Team at the Turner-Fairbank Highway Research Center and were primarily from the Northern Virginia area. All subjects were licensed drivers.

Table 2. Subject Composition

Age Group	Male		Female		Total	
	Age Range	Mean Age	Age Range	Mean Age	Age Range	Mean Age
Young	18-51	35.2	17-58	41.3	17-58	38.4
Old	60-84	73.4	61-86	72.0	60-86	72.7

As shown in the table above, the average age for young drivers was 38.4, roughly equivalent for both males and females with an overall mean of 38.4 years old for the younger group. The older group, with an average age of 72.7 years old, showed almost identical mean ages for males and females.

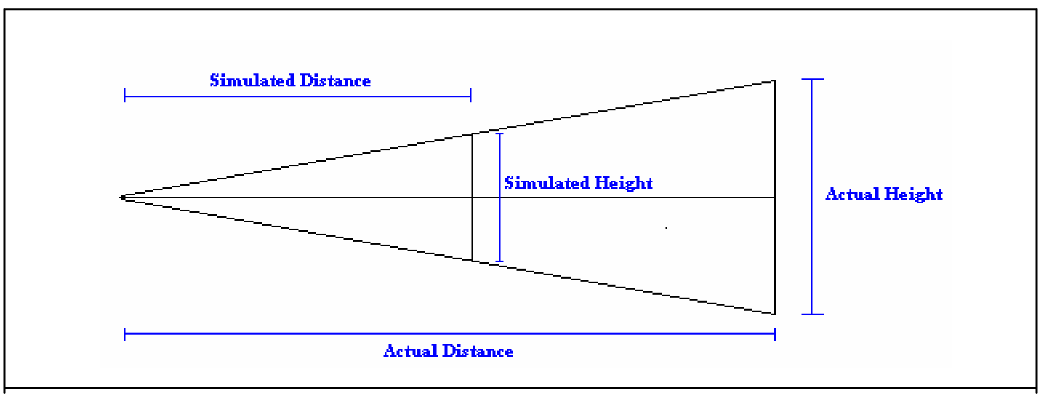
An information sheet completed by subjects at the conclusion of the experiment provided information on their current driving habits on freeways and toll roads. When broken down by sex, age, and age by sex, results show essentially no difference in the volunteers' experiences.

Virtually no subjects (8.5%) reported they own transponders for the Northern Virginia toll roads (Dulles Toll Road and Dulles Greenway). While they reported traveling on the area and regional toll roads on an infrequent basis, they were aware that lanes were dedicated for ETC use. Their experience reflected correct lane choice and use and did not have an impact on their understanding or perception of the signs.

Experimental Apparatus

The experiment was conducted in the Sign Simulator (SignSim) located at Turner-Fairbank Highway Research Center. This laboratory is used to present specific stimuli to participants in a highly controlled environment. The experiment used a computer-controlled slide projector that displayed the signs using a zoom lens at a simulated 35 miles per hour. The 35mm slides depicting on a rear-projection screen and subjects viewed the images from the front of the room. The overall relationship of determining the actual distances of signs displayed in the SIGNSIM is based on a known actual height of the sign, simulated distance, and voltage using the concept of similar triangles as shown in the Figure 2 (Katz, 2004). The actual height of the sign is a known value and the simulated distance is the distance between the participant's eye and the screen, in this case the distance was 114 inches.

Figure 2. Depiction of Simulated to Actual Sign Size Relationship



The similar triangles produced in the figure gives the relationship for determining the actual distance of the sign as:

$$\frac{\text{Simulated Distance}}{\text{Actual Distance}} = \frac{\text{Simulated Height}}{\text{Actual Height}}$$

which can be converted to:

$$\text{Actual Distance} = \frac{\text{Simulated Distance X Actual Distance}}{\text{Simulated Height}}$$

The next step was to determine what the simulated height of the sign was on the screen given various voltage readings from the SIGNSIM controller. The SIGNSIM zoom function for varying the size of the sign works using a servo-motor where voltages are fed into the zoom lens and then the size of the sign is increased.

By recording the voltages and measuring the height of the sign, the simulated height can be used to determine the actual distance using a regression equation with a fourth degree polynomial. The following equation was used to determine actual distances from voltages and produced an R^2 value of 0.9995 using an actual height of 4 feet. (A sample of the conversion table is displayed in Appendix C).

$$\text{Distance} = 4.796(\text{Voltage}^4) - 48.192(\text{Voltage}^3) + 212.65(\text{Voltage}^2) - 273.09(\text{Voltage}) + 432.43$$

Subjects pressed a response button to mark three separate events which were recorded as distances; 1) initial detection of the sign, 2) legibility of the guidance information, and 3) legibility of the pictograph. Subjects pressed a response button when they could first detect the sign, when they could read the guidance information, and when they could read the pictograph. When subjects pressed the button, the task was paused. Subjects were asked to read the guidance and pictograph information aloud and their answers (correct or incorrect) were recorded by the experimenter and stored on the computer with the distance information.

Experimental Procedure

Subjects were contacted by project staff and asked to volunteer for the experiment. If they agreed and met the age and sex criteria, an appointment was made for them to participate.

Subjects were met at the lobby of the TFHRC and escorted to the Sign

Simulator laboratory. There they were briefed regarding the experiment’s rationale and procedures. The subjects read and completed an informed consent form.

Subjects began the experiment seated 12.5 feet from the rear-projection screen in the SignSim. The experimenter explained to them that the experiment was being conducted to help the FHWA in designing signs and they were to look at the signs as shown on the screen and press the response button three different times. Subjects were to press the button for three different responses:

1. The first response indicated when they first saw the sign on the screen (Detection)
2. The second response indicated when they decided they could correctly read the guidance information (lane assignment) on the sign (Guidance Legibility) and then read it aloud.
3. The third response indicated when they decided they could correctly identify the pictograph on the sign (Pictograph Legibility) and then read it aloud.

Each subject was presented 60 slides, one-half of the total 120 signs. Each set of slides was randomly assigned to the subjects and the order of presentation was randomized to control for color combination and order effects.

The experiment began when the subject had completed a series of practice slides and felt comfortable with the experimental procedures. The experimenter displayed the first slide, which was a practice slide. The subject was then prompted to press the response button when s/he could read the guidance information and then was asked to read it aloud. Virtually all subjects read the guidance information correctly (97%). There was no difference in accuracy by sex or age. The sign’s voltage was recorded on the computer and the experimenter recorded if the subject’s reading of the information was correct. The screen would then darken for 2-4 seconds and the sign would be displayed again and zoom toward the subject staring from the point at which it had stopped. At that time the subject would press the button when s/he determined s/he could read the sign. The sign's distance at that point was recorded as well as whether s/he was correct on the pictograph. Subjects were not quite as accurate in their reading of pictograph information; overall 75% of the pictographs were read correctly with EZ TAG read correctly most often (84%), followed by E-ZPass and I-pass (76%), and then FasTrak (73%). Most errors occurred when the pictograph was paired with the black underlay.

After the 60 signs were presented, subjects were debriefed and given a short information sheet to complete and a thirty-dollar stipend. The information sheet requested information related to the subjects' driving experience, experience driving on toll roads and highways, and experience with electronic toll collection.

5. RESULTS

Section summarizes the results of the laboratory experiment. The results focus on each of the distance measures and are reported in feet, after conversion of the voltage measures used in the SignSim.

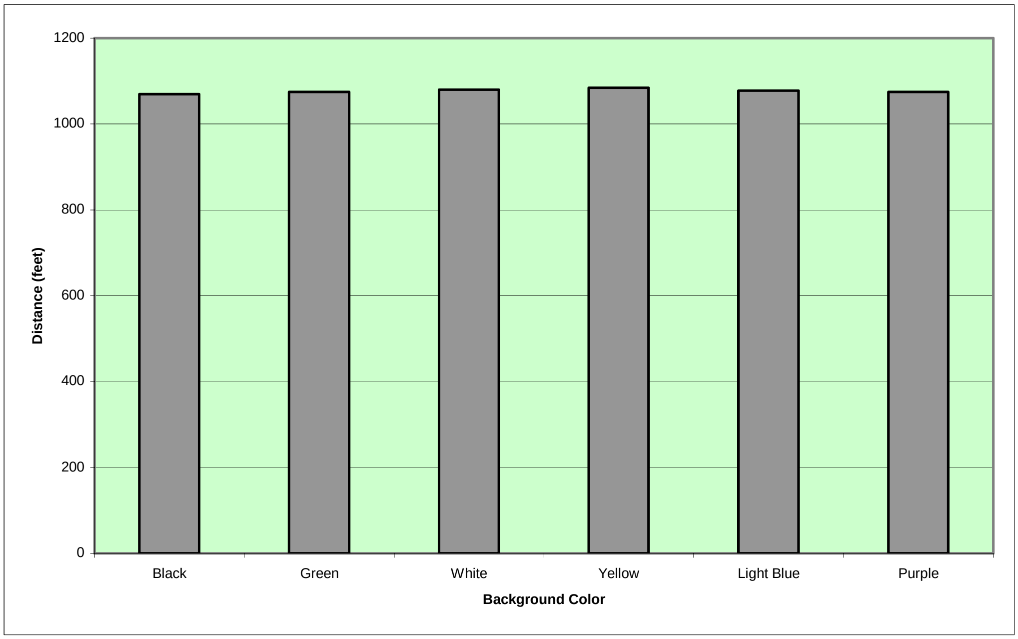
Detection Distance

Detection distance was defined as that point subjects were able to detect that a sign was on the screen. As the following figure shows, this distance averaged over 1,000 feet. This result can also be seen as the baseline for the next two legibility measures. This distance reflects when subjects could first detect the sign, not recognize or read it.

An analysis of variance test run to determine if any differences were obtained between the background colors was performed and resulted in an $F = 1.37$ $p < .09$, and showed no significant differences between the colors, though the signs with yellow, green, and white backgrounds obtained slightly higher detection distances.

Of course, signs do not consist only of a background color; and a sign's effectiveness is a result of the other elements, such as font color. Therefore, analysis proceeded with an assessment of the background and font color in combination.

Figure 3. Overall Sign Detection Distance.



Legibility Distance – Guidance Information

Analysis of the background and font colors showed that each element in isolation as well as the interaction of the two resulted in significant differences. For background color $t(5)=25.22$ $p<.0001$; for font, $t(3)=9.46$, $p<.0001$, and background*font yielded $F(5,3) =32.94$, $p<.0001$.

Tables 3, 4, and 5 summarize the distances obtained for background color, font color and the combination of background by font color.

No differences were found by the lane assignment message; 2 Left Lanes vs. 2 Right Lanes vs. Right Lane vs. Left Lane. Subjects were able to read each of the messages equally well.

Table 3. Summary of Background Color – Legibility Distance Guidance Information

Background Color	Mean Legibility Distance	Standard Deviation
Black	438	138
Green	456	148
White	405	136
Yellow	399	129
Light Blue	384	160
Purple	398	148

As shown, signs with a green background, were able to be read from the longest distance, followed by black, white, and yellow. Of interest is that these signs reflect current practices for general signing.

Table 4. Summary of Font Color – Legibility Distance Guidance Information

Font Color	Mean Legibility Distance	Standard Deviation
Black	410	152
Green	420	137
White	417	136
Yellow	398	160

When considering font alone, white and green were essentially equal, followed by black and yellow. Again, these correspond roughly to current practices and as shown in Table 6 and Figures 4 through 9, also depict the effect of contrast between background and font colors.

As shown in Table 6, those sign combinations with the highest contrast between background color and font color were able to be seen from the farthest distance. Of interest, again, is that the combination of yellow font on a green background was seen from the greatest distance, though current practices of white on green was essentially equal. Non-standard combinations of white on purple, light blue on black and purple on yellow also obtained high distance measures, again reinforcing the impact of high contrast between the two elements.

Table 5. Summary of Background by Font Color – Legibility Distance Guidance Information

Background Color	Font Color			
	Black	Green	White	Yellow
Black		422	437	457
Green	415		474	486
White	435	438		344
Yellow	430	426	342	
Light Blue	462	444	368	262
Purple	310	373	467	443

The following figures graphically depict the distances obtained by each background and font combination.

Figure 4. Legibility Distance - Black Background by Font Color

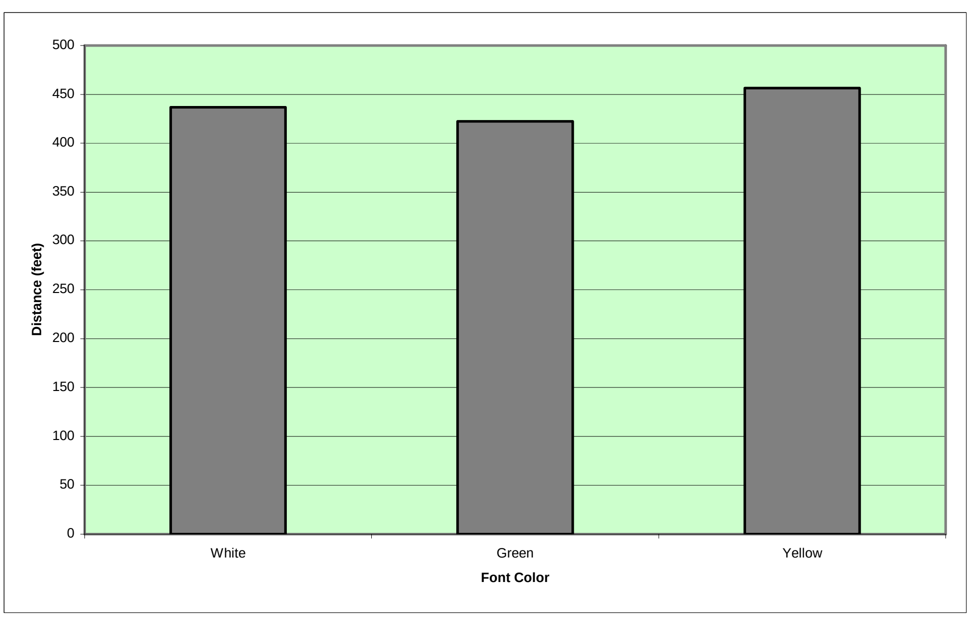


Figure 5. Legibility Distance - Green Background by Font Color

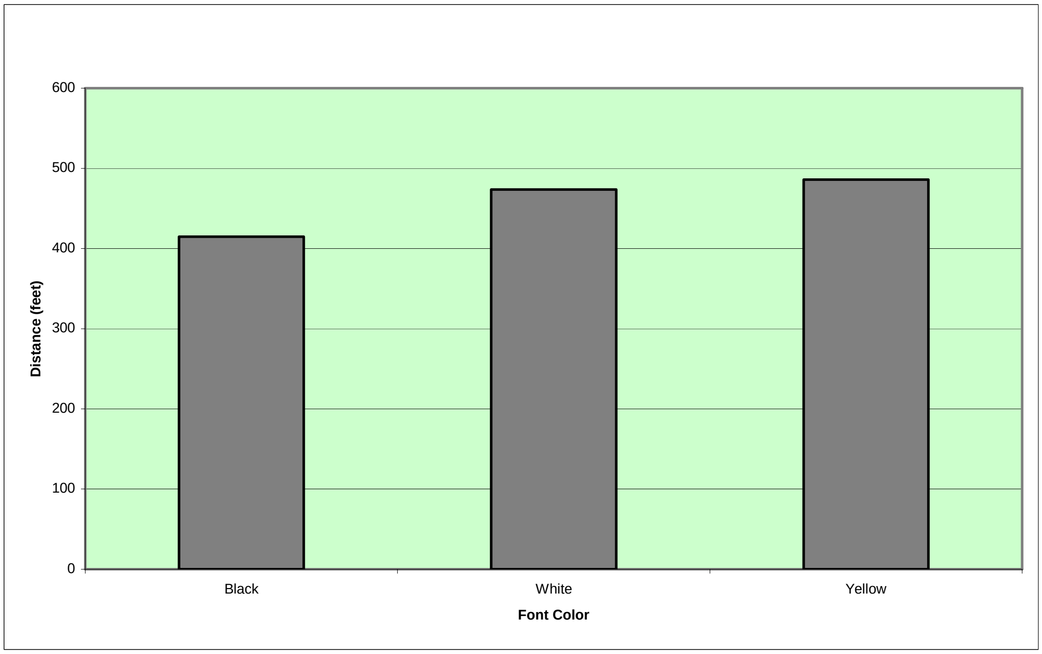


Figure 6. Legibility Distance - White Background by Font Color

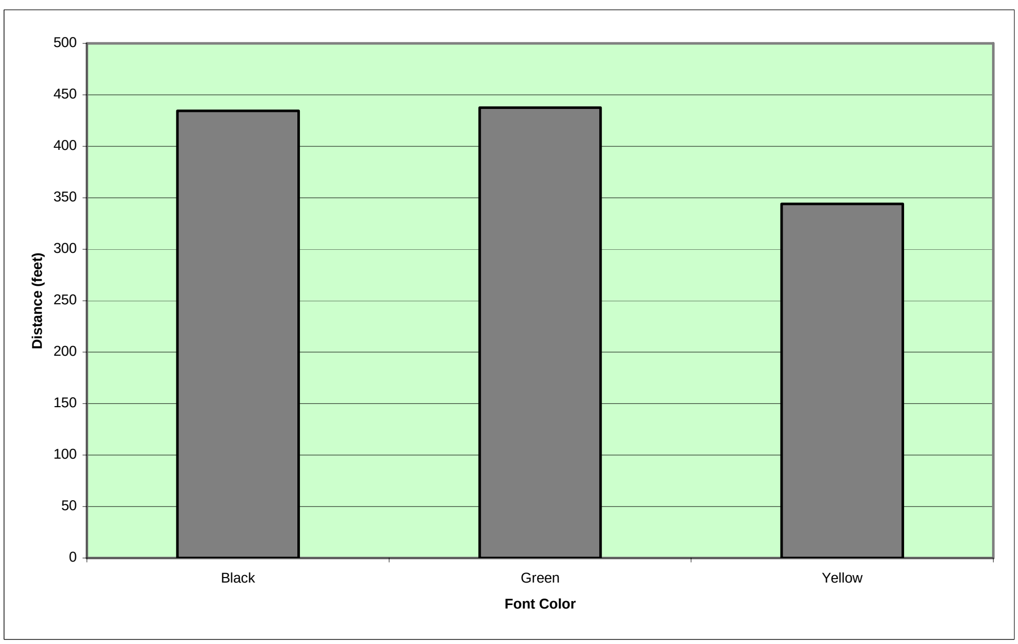


Figure 7. Legibility Distance - Yellow Background by Font Color

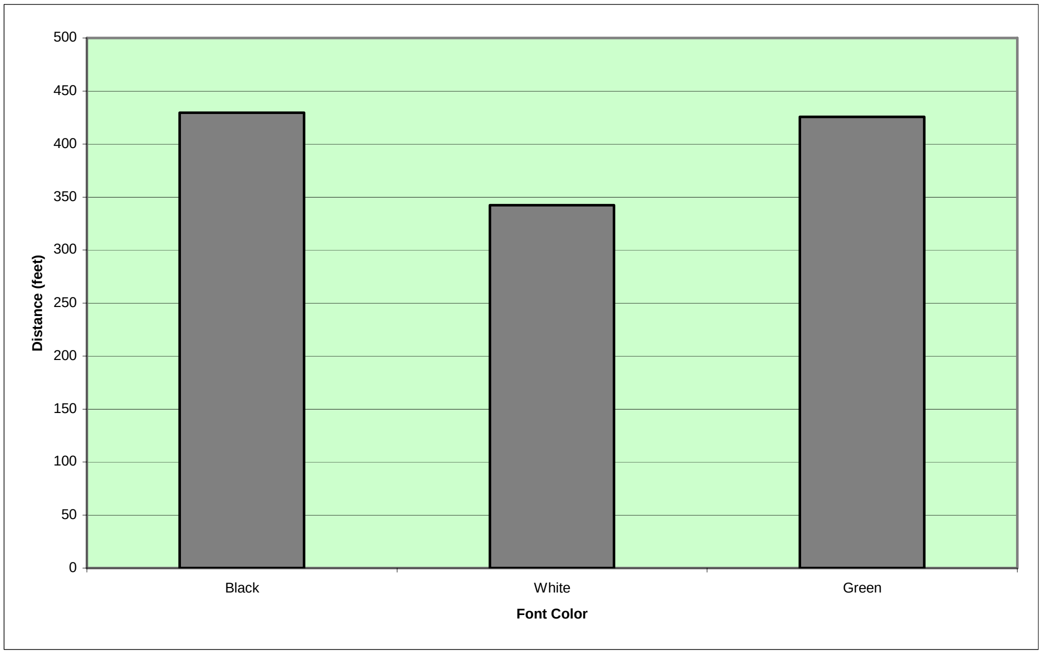


Figure 8. Legibility Distance - Blue Background by Font Color

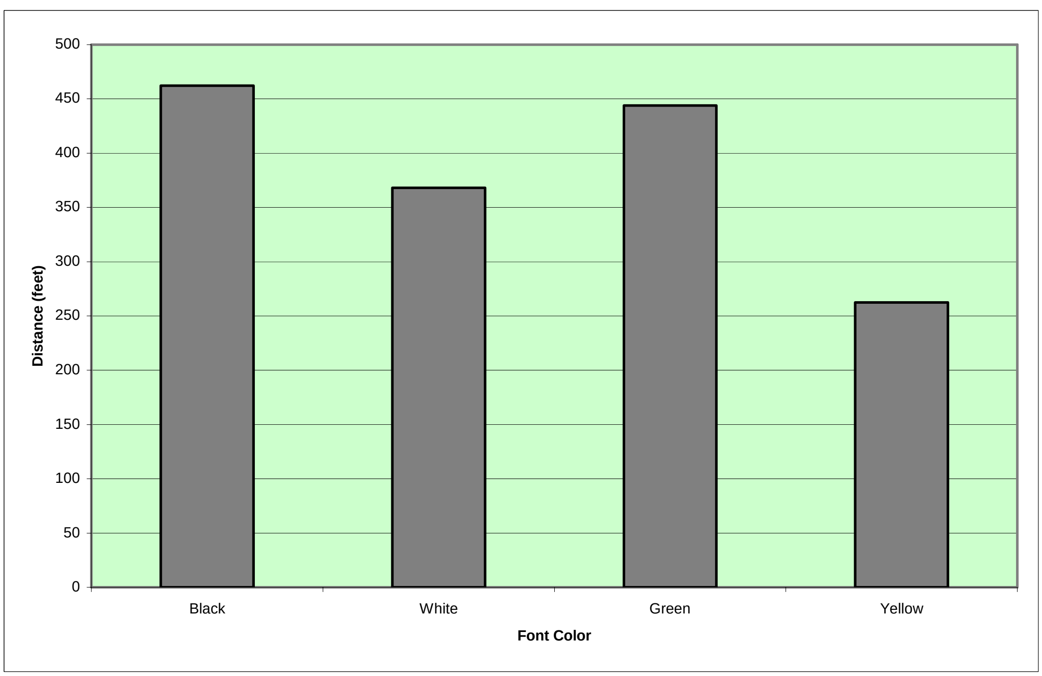
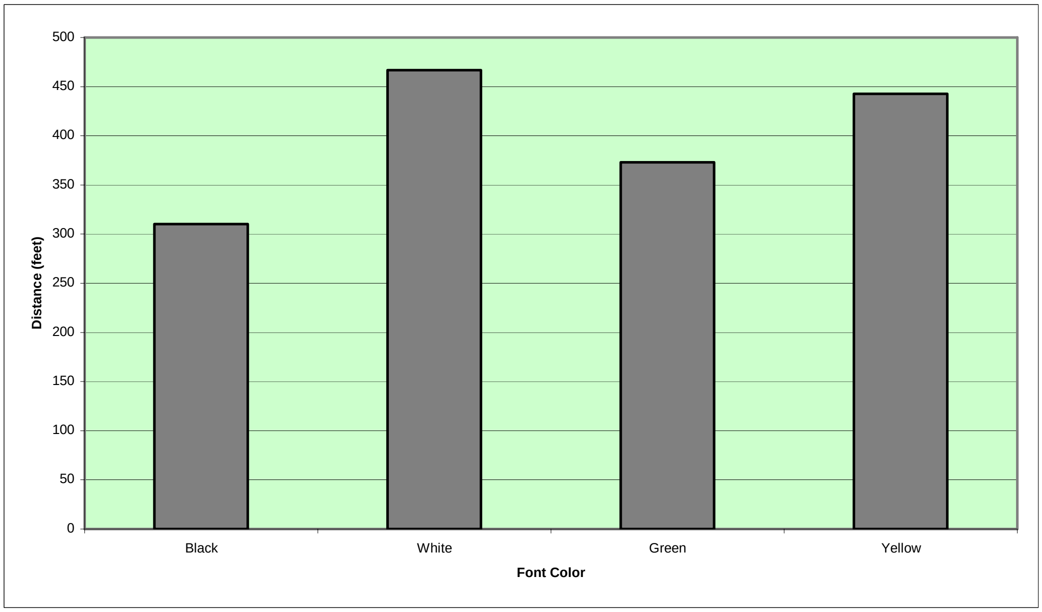
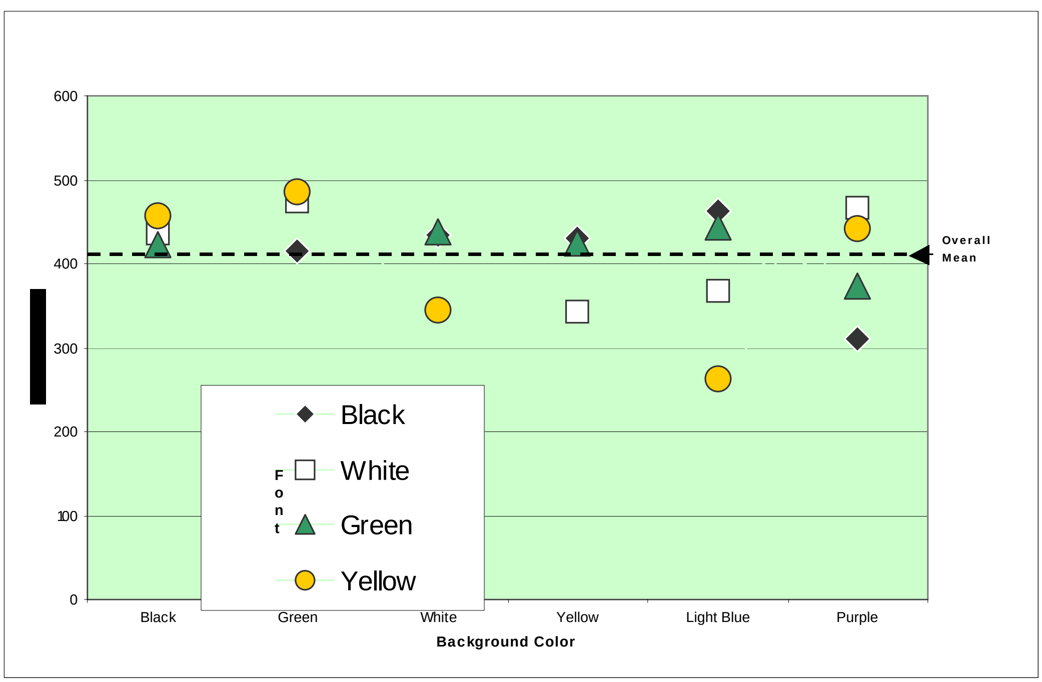


Figure 9. Legibility Distance - Purple Background by Font Color



Finally, when comparing the combination of all elements, Figure 10 (below) supports the design guidelines of high contrast between the background

Figure 10. Legibility Distance - Comparison of All Combinations Background and Font Colors



color and the font color. Those signs with the highest contrasting elements obtained distances significantly higher than those with low contrast and reinforce the current design convention of a white colored font on a green background.

Also of interest is that a comparison by age showed that older subjects' responses showed a significantly shorter legibility distance, $t(1) = 88.6$, $p<.0001$. The overall difference between the older and younger groups was approximately 10 %. The older subjects were able to read the signs at 4,608 feet while younger subjects averaged 5,154 feet. These results were relatively constant over all background and font colors.

This finding is consistent with other studies and might indicate that older drivers may require more frequent signage to insure they are guided to the correct lanes further downstream. This recommendation would, of course, help all drivers.

Legibility Distance - Pictographs

When considering legibility distance for reading the pictographs, the pictograph design itself, the underlay color, and the sign's background color were all assessed. These elements were seen as most critical to alert drivers, especially non-locals to an upcoming toll plaza and ETC lanes. It is important to remember that all pictographs in this experiment were purple, therefore, the only factor under consideration for this element was the design.

Analysis of these variables found all to be significant factors related to the legibility distance. Analyses of variance yielded the following results; Background color – $t(5)=23.42$, $p< .0001$; Underlay color – $t(5) = 37.36$, $p<.0001$; and Pictograph $t(5) = 87.44$, $p<.0001$. Tables 6, 7, and 8 summarize the legibility distances for the background, underlay, and pictographs.

Table 6. Pictograph Legibility Distance - Background Color

Background Color	Mean Legibility Distance	Standard Deviation
Black	188	88
Green	217	112
White	166	105
Yellow	183	90
Blue	178	99
Purple	194	99

As shown, again, the green background color yielded the farthest legibility distance measurements, similar to the results of the guidance information. This lends further support to the current common practice of using green as the background color. However, dark colored signs, such as purple and black also fared well.

Table 7. Pictograph Legibility Distance - Underlay Color

Underlay Color	Mean Legibility Distance	Standard Deviation
Black	159	99
Green	165	81
White	213	101
Yellow	203	102
Blue	210	107

Owing to the dark (purple) color of the pictograph, the underlay colors shown as most effective were those that were lighter and have a high contrast to purple. The most effective were white, light blue, and yellow. Conversely, black and green yielded significantly lower distances. Purple was not included in this analysis since a purple underlay with a purple pictograph would be viewed as a blank purple field.

Finally, as shown in Table 9, subjects were able to read the EZ TAG pictograph at a much longer distance than any of the other alternatives. This

Table 8. Pictograph Legibility Distance – Pictograph Type

Pictograph	Mean Legibility Distance	Standard Deviation
EZ TAG	268	117
E-ZPass	178	98
FasTrak	157	72
I-Pass	193	92

finding may be due to the relative simplicity of the design, since it is just text, as well as to the relatively high ratio of the pictograph to the underlay color. The EZ TAG pictograph has relatively more "empty" space that helps to separate the figure from ground (i.e., the pictograph from its background color). The designs of E-ZPass and I-Pass are more stylized, and appear to take longer to process. Similarly, the FasTrak logo also contains more design elements.

Focusing on the underlay/pictograph combinations, Table 10 summarizes the legibility distances for each and is followed by a series of figures that shows the relationships between the two elements.

Table 9. Pictograph Legibility Distance - Underlay Color and Pictograph

Pictograph	Underlay Color				
	Black	Green	White	Yellow	Blue
EZ TAG	202	210	282	295	326
E-ZPass	137	158	216	199	175
Fast-Trak	124	146	188	176	162
I-Pass	150	186	188	193	202

As shown, distances for EZ-TAG were greater than for any other pictograph, even when compared across all underlay colors. This was especially apparent for the lighter colors (with greater contrast) such as blue, yellow, and white. In fact, a light blue underlay paired with the purple pictograph yielded legibility distances of between 40% and over 100% better than the other pictographs. Also of note, is the relatively high distance of EZ-TAG even with a black (low contrast) background color.

Figure 11. EZ-TAG by Underlay Color

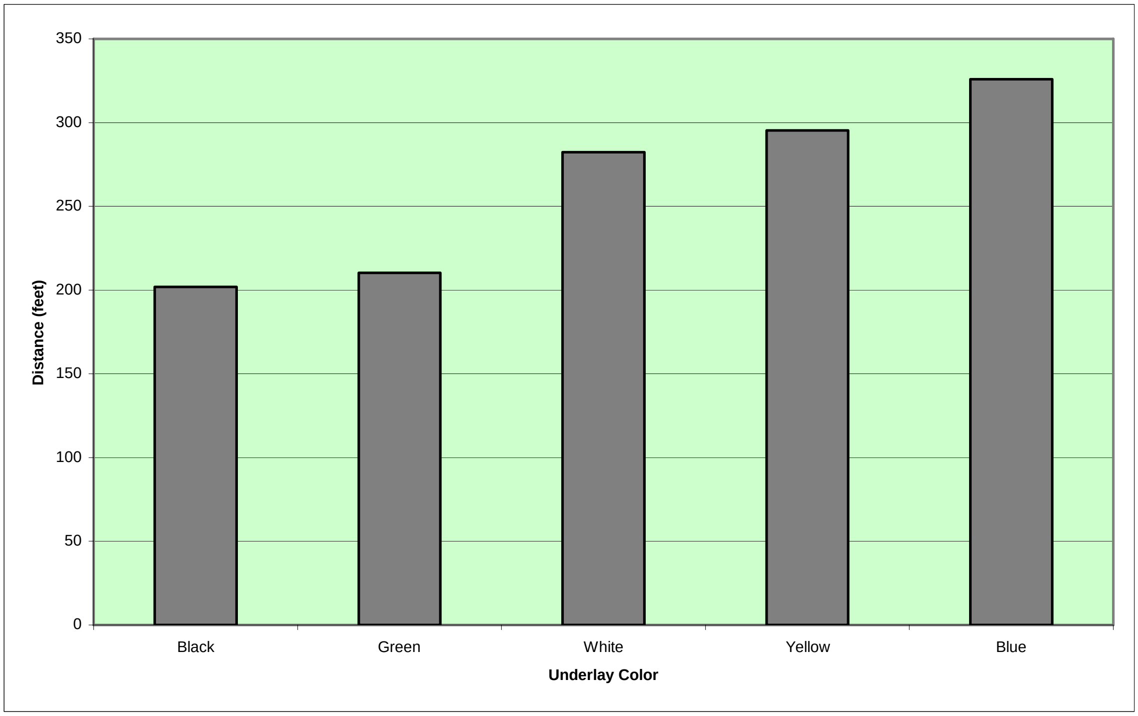


Figure 12. E-ZPass by Underlay Color

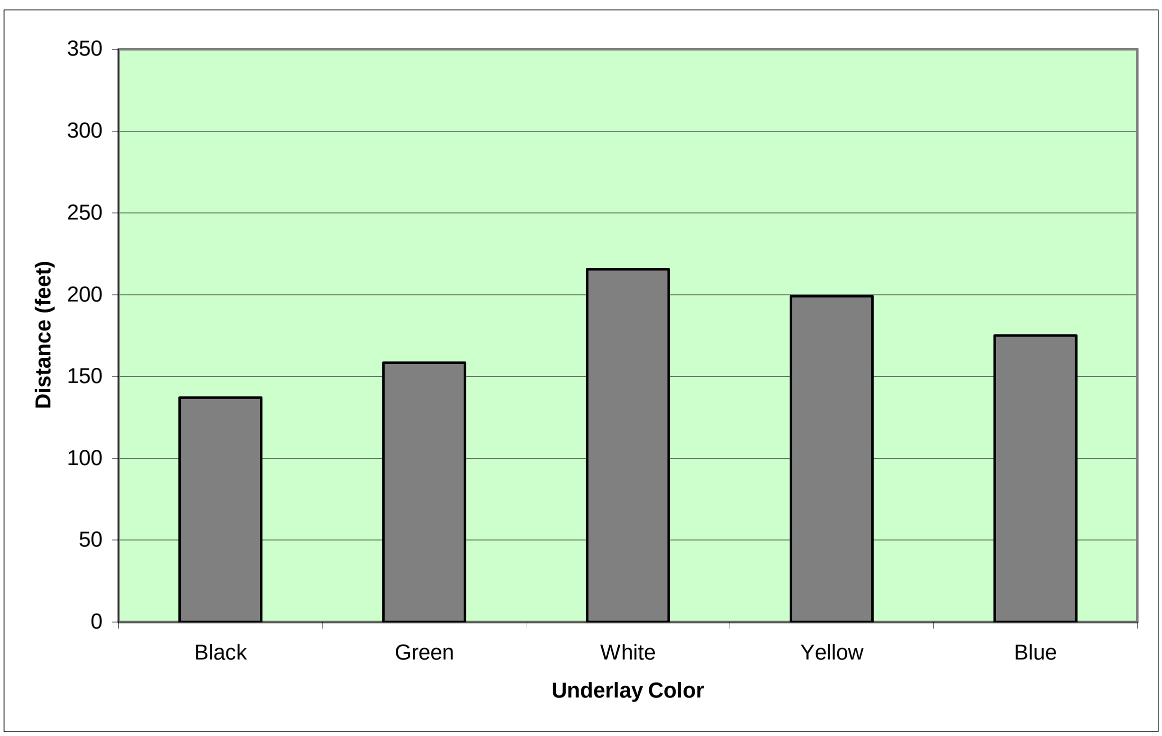


Figure 13. FasTrak by Underlay Color

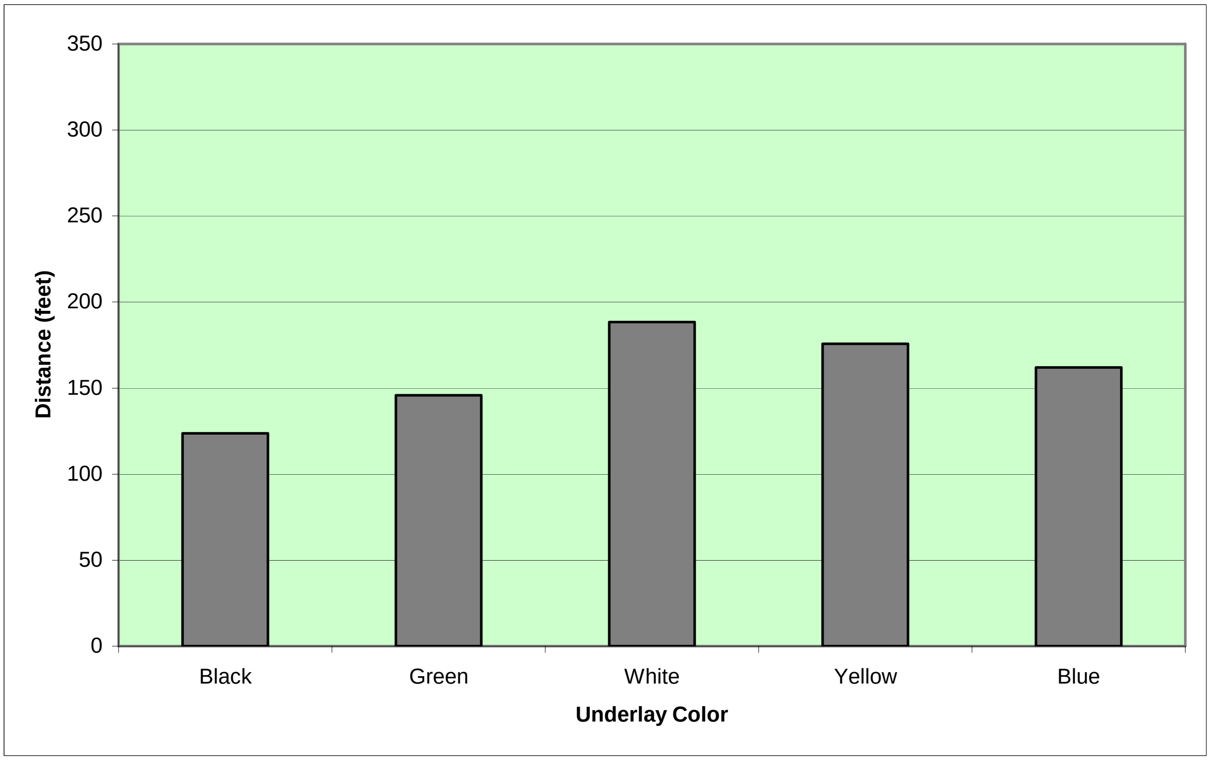
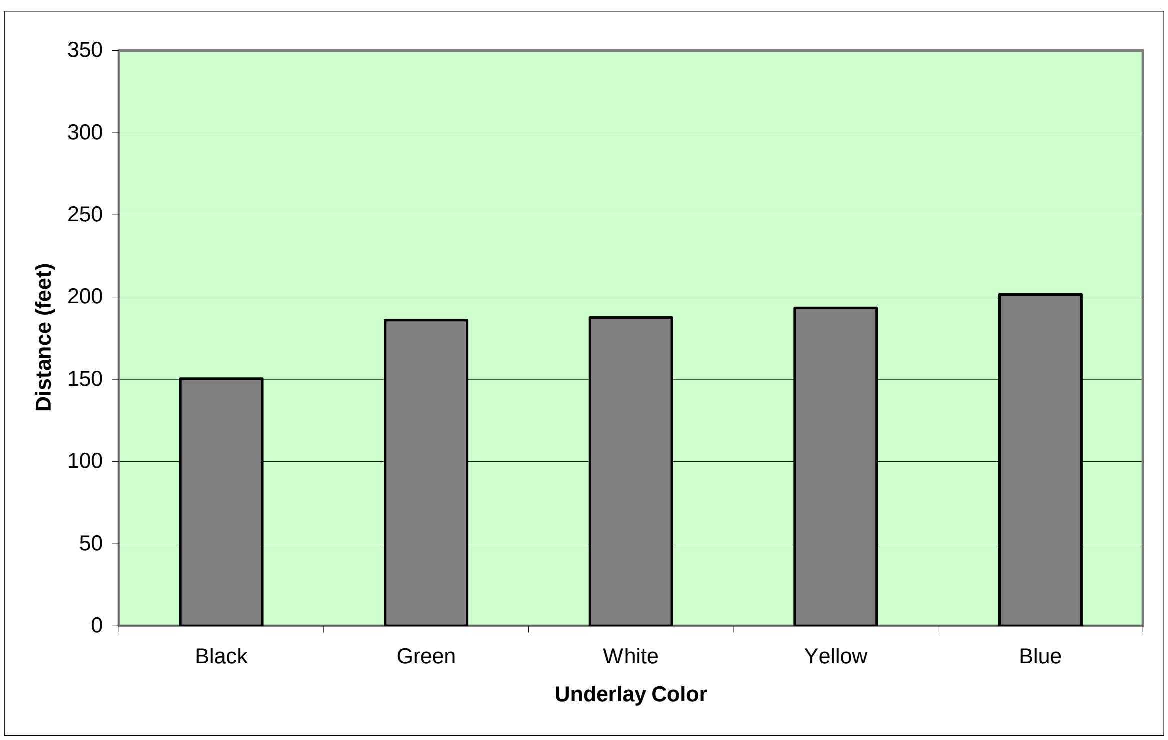
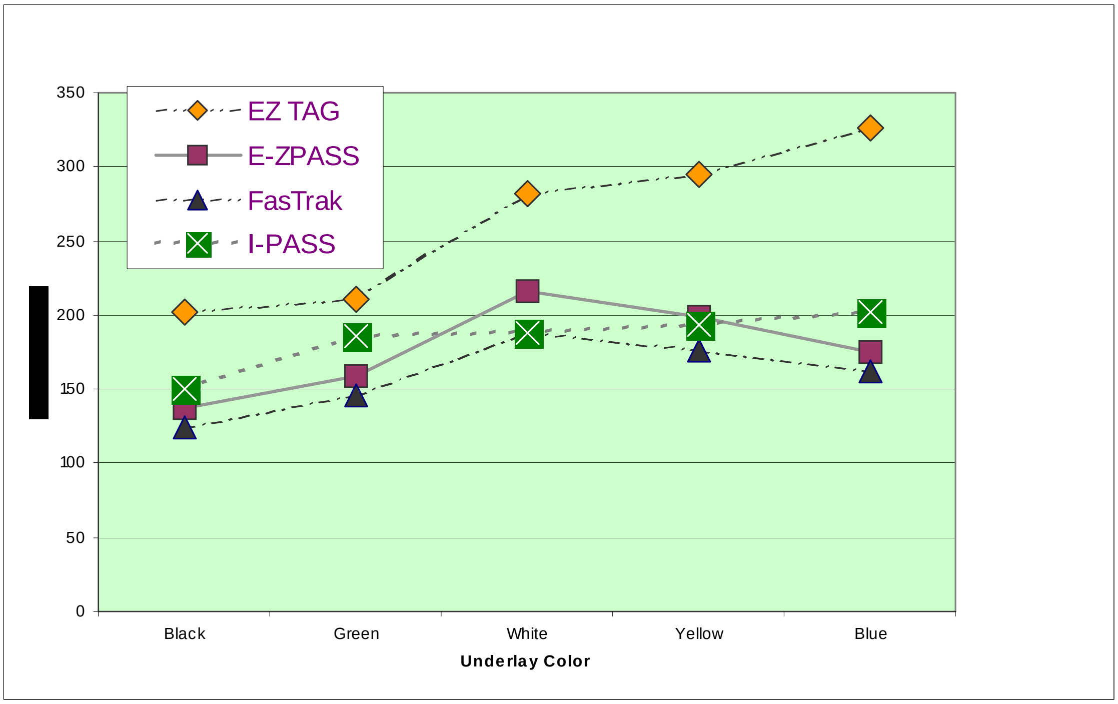


Figure 14. I-Pass by Underlay Color



The following chart depicts the combination of all pictographs with underlay colors and demonstrates the significantly longer distances obtained with

Figure 15. Pictograph Legibility Distance - Summary of All Pictographs by Underlay Color



the EZ TAG pictograph. This generally supports the view that "the simpler the better," when considering the designs to be used on toll roads.

In addition, similar to the analysis on background color and font, significant differences were also found for pictograph legibility distance between the older and younger subjects ($t(1) = 84.6$, $p<.0001$). The magnitude of the difference was even more striking with a difference of almost 20% between overall legibility distance (across all underlay colors and pictographs). These differences were most apparent with the E-ZPass, I-Pass, and FastTrak pictographs, though still evident with the EZ TAG pictograph.

6. CONCLUSIONS and RECOMMENDATIONS

This experiment was conducted to help determine general design guidelines to be used when considering signage on toll roads that support electronic toll collection (ETC). Six different background colors were used in combination with four font colors, and four toll road ETC pictographs currently in use.

Consistent with current guidance signing practices, the green background sign with a white font was shown to have significantly long legibility distances for the guidance information. Other combinations that also showed high contrast such as purple and black backgrounds with white or yellow fonts also obtained long distances but, when considering current practices and guidelines, would not warrant implementation.

Similar to the background and font color combinations, the color that is under the toll road pictograph (underlay) and the pictograph design also appear to significantly effect legibility distance. Subject's responses to the different pictograph designs showed that the EZ TAG pictograph could be read from a significantly farther distance than the others tested (E-ZPass, I-Pass, and FastTrak). This was interpreted as being due to its relative simplicity and ratio of figure to ground, especially when compared to light colored underlay colors (though this pictograph performed much better with all underlay colors).

Finally, consistent with other research involving older drivers, the older subjects obtained significantly longer legibility (though not detection) distances than their younger counterparts. Overall differences ranged from approximately 10% for the guidance information legibility distance to approximately 20% for the pictograph legibility distance. The differences were consistent across combinations of colors and elements.

Based on these results, the following recommendations are offered : (assuming the pictographs remain purple, as tested in this study)

- Green is the established guidance sign color. Its effectiveness in this study shows it should be retained and the font color should remain white.
- Purple as “the” pictograph color appears to be a good choice but only if its underlay is a highly contrasting color such as white or green or as shown in this study – light blue.
- This study shows there is some evidence that “more stylized” pictographs can be difficult to read, especially at farther distances and for drivers who may be new to the toll facility. It is recommended that to help drivers read these, the type of design be carefully considered, especially to allow a high underlay to pictograph ratio or to simplify the new pictographs, when possible.
- Finally, the research supports other research showing older drivers need more time to perceive and process information. This information should be considered for guidelines on sign placement and frequency along toll roads.

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The Washington Post (2003) Dr. Gridlock, November 9, Section C, Page 2.

Appendix A – Sample Signs from Toll Roads

E-ZPass – New York/New Jersey

E-ZPass – West Virginia

E-ZPass - Maryland

Palmetto Pass – South Carolina

EZ TAG - Texas

FasTrak - California

I-Pass - Illinois

Appendix B – Examples of Experimental Stimuli Signs


PASS
LEFT LANE
TOLL PLAZA 1 MILE


E-ZPass
LEFT LANE
PAY TOLL 1 MILE


EZ TAG
2 LEFT LANES
TOLL PLAZA 1 MILE

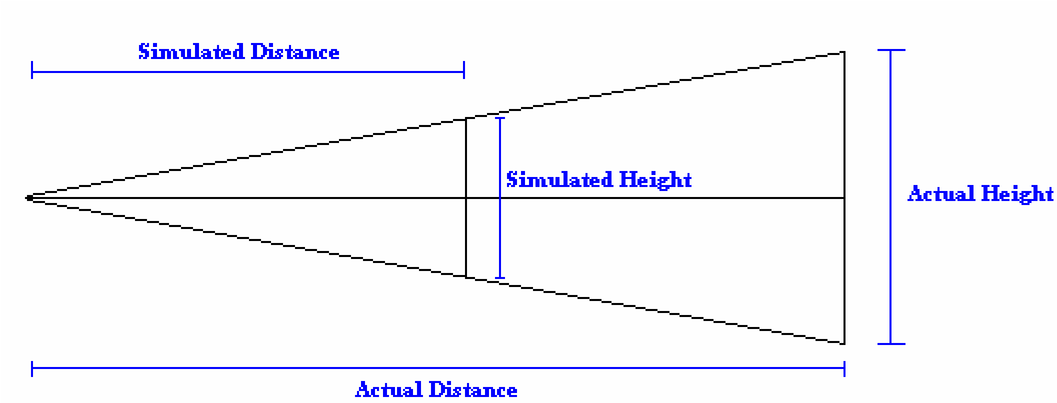

E-ZPass
LEFT LANE
PAY TOLL 1 MILE


PASS
2 LEFT LANES
PAY TOLL 1 MILE


FASTRAK
2 LEFT LANES
PAY TOLL 1 MILE

Appendix C – Example of Voltage to Distance Conversion

The overall relationship of determining the actual distances of signs displayed in the SIGNSIM based on a known actual height of the sign, simulated distance, and voltage is based on the concept of similar triangles as shown in the following figure. The actual height of the sign is a known value and the simulated distance is the distance between the participant's eye and the screen, in this case the distance was 114 inches.



The similar triangles produced in the figure gives the relationship for determining the actual distance of the sign as:

$$\frac{SimulatedDistance}{ActualDistance} = \frac{SimulatedHeight}{ActualHeight}$$

which can be converted to

$$ActualDistance = \frac{SimulatedDistance \times ActualDistance}{SimulatedHeight}$$

The next step was to determine what the simulated height of the sign was on the screen given various voltage readings from the SIGNSIM controller. The SIGNSIM zoom function for varying the size of the sign works using a servo motor where voltages are fed into the zoom lens and then the size of the sign is increased.

By recording the voltages and measuring the height of the sign, the simulated height can be used to determine the actual distance using a regression equation with a fourth degree polynomial. The following equation was used to determine actual distances from voltages and produced an R^2 value of 0.9995 using an actual height of 4 feet.

$$\text{Distance} = 4.796(\text{Voltage}^4) - 48.192(\text{Voltage}^3) + 212.65(\text{Voltage}^2) - 273.09(\text{Voltage}) + 432.43$$

The following figure shows a sample output from the spreadsheet used to calculate the equation.

Toll Road Sign Project
Sign Stimulus (Slides) Actual Screen Size by Voltage

Actual Height	48	4
Simulated Dist	114	

	Sign		
Voltage	**Width**	**Height**	**Actual Dist**
0.75	26.375	17.625	310.4680851
1.00	24.875	16.625	329.1428571
1.25	23.250	15.500	353.0322581
1.50	21.750	14.500	377.3793103
1.75	20.250	13.500	405.3333333
2.00	18.750	12.625	433.4257426
2.25	17.375	11.688	468.1724846
2.50	16.000	10.750	509.0232558
2.75	14.688	9.875	554.1265823
3.00	13.500	9.250	591.5675676
3.25	12.250	8.375	653.3731343
3.50	11.250	7.500	729.6
3.75	10.125	6.875	795.9272727
4.00	9.375	6.125	893.3877551
4.25	8.500	5.500	994.9090909
4.50	7.625	4.938	1108.140948
4.75	6.875	4.500	1216
5.00	6.000	4.000	1368
5.25	5.250	3.625	1509.517241
5.50	4.625	3.188	1716.436637
5.75	4.125	2.750	1989.818182
6.00	3.625	2.375	2304
6.25	3.250	2.125	2575.058824
6.50	2.875	1.875	2918.4
6.75	2.625	1.625	3367.384615
7.00	2.250	1.375	3979.636364