FINAL
CONTRACT REPORT

IMPROVEMENT OF CONSPICUITY OF TRAILBLAZING SIGNS: PHASE III—EVALUATION OF FLUORESCENT COLORS

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16. Abstract

This report represents a Phase III effort to design and evaluate a new sign design for incident route trailblazing. The colors evaluated were fluorescent coral, fluorescent purple, fluorescent yellow-green, and non-fluorescent purple. The results indicate no significant differences in driving performance with regard to the four experimental sign color combinations. Regarding the subjective preference questionnaires, significant questionnaire results along with trend information suggest that black on fluorescent yellow-green was the most preferred by younger and older drivers during both day and night visibility conditions. Nonetheless, this sign color has been assigned by FHWA for pedestrian, school, and bicycle crossings, which eliminated the opportunity to use fluorescent yellow-green as a unique sign color for trailblazing in incident management situations. Preference for non-fluorescent yellow on purple consistently increased at night when the sign became more luminant; however, the overall preference for this sign color combination was lower than for the other sign color combinations tested in this study. With the elimination of these two signs, the remaining contenders for a unique sign color combination were black on fluorescent coral and fluorescent yellow on fluorescent purple. Black on fluorescent coral was ranked significantly higher than fluorescent yellow on fluorescent purple for visibility and for overall preference. Questionnaire trend information suggests that black on fluorescent coral was more preferred than fluorescent yellow on fluorescent purple during daytime viewing conditions and less preferred than fluorescent yellow on fluorescent purple during nighttime viewing conditions. The overlay film used for the fluorescent coral sign was a first generation material that can reasonably be expected to result in improved nighttime luminance when produced in a full production run. In addition to the study results, drivers commented that the arrow on the sign was too small to determine directional information from a comfortable distance.

Based on such driver comments, the research conclusions, and the federal regulations enacted since the outset of this series of experiments, the following recommendations are made: (1) black on fluorescent coral should be used as a unique incident management sign color, and (2) the directional arrow on the sign should be larger.

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agency.)

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ABSTRACT

This report represents a Phase III effort to design and evaluate further a new sign design for incident route trailblazing. A serious limitation of Phases I and II (Neale et al., 1999) was that fluorescent colors were not evaluated. Laboratory research and anecdotal evidence suggest that the use of fluorescent colors on signs improves their conspicuity. Therefore, in Phase III, the following colors were evaluated along a contrived test route with an instrumented vehicle: black on fluorescent coral, fluorescent yellow on fluorescent purple, black on fluorescent yellow-green, and yellow on purple in non-fluorescent colors.

The results indicate that there were no significant differences in driving performance among the four experimental sign color combinations. Regarding the subjective preference questionnaires, significant questionnaire results along with trend information suggest that the black on fluorescent yellow-green sign was the most preferred by younger and older drivers during both day and night visibility conditions. Nonetheless, this sign color has been assigned by the Federal Highway Administration for pedestrian, school, and bicycle crossings, which has eliminated the opportunity to use fluorescent yellow-green as a unique sign color for trailblazing in incident management situations. Preference for the non-fluorescent yellow on purple sign consistently increased at night when the sign became more luminant; however, the overall preference for this sign color combination was lower than for the other sign color combinations tested in this study. With the elimination of these two signs, the remaining contenders for a unique sign color combination were black on fluorescent coral and fluorescent yellow on fluorescent purple.

Black on fluorescent coral was ranked significantly higher than fluorescent yellow on fluorescent purple for visibility and for overall preference. Questionnaire trend information suggests that black on fluorescent coral was more preferred than fluorescent yellow on fluorescent purple during daytime viewing conditions and less preferred than fluorescent yellow on fluorescent purple during nighttime viewing conditions. The overlay film used for the fluorescent coral sign was a first generation material that can reasonably be expected to result in improved nighttime luminance when produced in a full production run. In addition to the study results, drivers commented that the arrow on the sign was too small to determine directional information from a comfortable distance.

Based upon such driver comments, the research conclusions, and federal regulations that have been enacted since the outset of this series of experiments, the following recommendations are made:

1. Black on fluorescent coral should be used as a unique incident management sign color.

2. The directional arrow on the sign should be larger.

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INTRODUCTION

Drivers navigating around traffic incidents are often diverted from the primary route onto a secondary street system and then back to the primary route. Diversion routes need to be marked, or "trailblazed," in a conspicuous manner so motorists unfamiliar with the area can navigate the alternate route, regardless of the driving environment or visibility condition. Furthermore, traffic signs must be recognized and understood quickly to allow sufficient time for decision making and appropriate action relative to the changing combination of driving conditions.

There is a host of issues that affect the design of a trailblazing sign. Problems such as increased driver workload associated with navigating through a trailblazed area may affect the driver attending to the vehicle path, identifying trailblazing signs, reading the message, understanding its meaning, and deciding what action to take based on his or her interpretation of the sign's meaning. A contributing factor to this problem may be that the "EMERGENCY DETOUR" sign currently used for trailblazing employs the black on orange color scheme that is associated with construction activities; however, research results (e.g., Pietrucha, 1993) indicate that there should be a separate category of traffic signs (i.e., independent of construction signs) to control traffic in an emergency situation.

Another issue in the design of a trailblazing sign is driver characteristics and individual differences. For example, the age range of the driving population is of primary concern. Elderly drivers may experience more stress than drivers of other age groups, which reduces the amount of attention they can devote to detecting, reading, and responding to traffic signs and other traffic control devices and which can increase decision times (Dewar, 1989, 1993; Hiatt, 1987; Mortimer & Fell, 1989). In addition, many older persons require higher levels of contrast to identify and discriminate real-world targets, including traffic signs (Owsley & Sloane, 1987). These characteristics require that a traffic control device provide older drivers with more information and more time to respond than younger drivers (Mortimer & Fell, 1989). Similarly, younger drivers may also need more time to respond to traffic control devices, although for other reasons. Younger drivers tend to have a lower risk perception than older drivers (Finn & Bragg, 1986) that, when coupled with their driving inexperience, leads to a high probability for a crash to occur.

Nighttime visibility conditions must also be considered in the design of a trailblazing sign or other traffic control device. The visibility and conspicuousness of road signs decrease significantly at night, with the problem being more pronounced for older drivers (e.g., Collins, 1989; Verriest, 1963). Glare in the driver's eyes because of oncoming headlights and reduced visibility because of weather conditions are also of concern.

There are also several design issues concerning the legibility distance and reaction time that are associated with a traffic sign (e.g., Dewar, 1988, 1989, 1993; Mace, 1988; U.S. Department of Transportation, 1983), such as the following:

- shape coding and sign size
- understandability of symbols
- proximity of borders
- illumination
- stroke width
- spacing between letters
- letter fonts and size
- uniformity of design
- sign positioning
- luminance of the sign
- retroreflectivity
- legend
- contrast
- color coding and color combinations.

This list, although not comprehensive, demonstrates that there are many design issues that will affect the usefulness of a traffic sign, even under ideal viewing conditions. With this information in mind, a three-part experiment was initiated by the Statewide Incident Management (SIM) Committee of Virginia and the Virginia Transportation Research Council because of problems experienced when an incident detour marked with black on orange detour signs was overlapped with a construction detour that was also marked with black on orange detour signs. Members of the SIM Committee felt that the inability of the motorist to determine which sign to follow prompted the need for a unique sign color to trailblaze motorists around an incident. They further thought that a unique sign color for an incident detour would reduce motorist confusion, give the driver a higher "level of comfort" while navigating an unfamiliar area, and improve operational safety and efficiency by reducing sudden stops and erratic maneuvers.

Summary of Phase I

Phase I was an off-road field experiment conducted to evaluate the four sign background colors that are currently reserved by the *Manual on Uniform Traffic Control Devices* (MUTCD) (coral, light blue, purple, and strong yellow-green) with a host of legend colors. Also evaluated were the current standard black on orange emergency sign and a red, white, and blue sign. The legend colors chosen were based on analyses of luminance contrast and color contrast with the background colors. In total, 13 color combinations were evaluated:

1. black on orange
2. black on coral
3. blue on coral
4. white on coral
5. black on light blue
6. blue on light blue
7. yellow on light blue
8. black on purple
9. white on purple
10. yellow on purple
11. black on yellow-green
12. yellow-green on purple
13. red on white and white on blue on the same sign.

The last color combination represents a red, white, and blue sign that was under consideration for use in Northern Virginia. Note that fluorescent colors were not evaluated.

The independent variables in Phase I were sign color combination, letter stroke width, and letter size. The 13 color combinations were evaluated using two letter series, C and D (which were used to investigate letter stroke width ratio values of 0.14 and 0.16, respectively), and two letter sizes, including 100 mm (4 in) and 125 mm (5 in). Other independent variables included age (young and older) and visibility condition (daytime or nighttime). Factors that were experimentally controlled were (1) gender; (2) color vision, (3) daytime cloud conditions (i.e., clear versus cloudy), and (4) time of day. Furthermore, presentation of the signs was varied systematically to account for the position of the sun in reference to the sign. The dependent variable of interest was legibility distance of the sign (or distance required to read) including determination of the sign arrow direction.

Test signs were manufactured using the 3M Company's Scotchlite™ Transparent Process Color and Scotchlite™ Diamond Grade Reflective sheeting. The background colors were fabricated by traditional silk screening. Text legends, arrow icons, and sign borders were applied either by silk screening, non-reflective black tape, or yellow Scotchlite™ Diamond Grade Reflective sheeting, depending on the legend color used. Test signs measured 0.610 m (24 in) by 0.762 m (30 in).

Sixteen drivers participated in this off-road field experiment. Nine of the drivers were aged 18 to 28, one driver was age 42, and six drivers were aged 67 to 75. A 1995 Oldsmobile Aurora was used as the observation vehicle. The study was conducted on an isolated test strip at the Virginia Tech airport in Blacksburg, Virginia. Twenty-seven test signs featuring the 13 color combinations, combinations of the letter heights and letter series, and directional arrows were posted at alternate ends of the 296.7-m-long (970-ft) test strip. Participants were driven toward the test signs until they were able to read each line of text (random words made up of letters that were geometrically representative of the letters in "EMERGENCY DETOUR") and determine the arrow direction. Each legend or arrow reading was considered a unique measurement. Following each sign presentation, participants were asked to give a subjective rating of the sign's legibility.

Phase I revealed that several of the sign color combinations resulted in legibility distances that were superior to those for black on orange. Of these, three were chosen for an on-road test of conspicuity: black on coral, black on light blue, and yellow on purple. Furthermore, the results indicated improved legibility distances for signs employing the D series, 125-mm (5-in) (stroke width ratio = 0.16) letters. Based on the results of Phase I, an on-road test and evaluation of the traffic signs was employed to determine conspicuity of the new sign designs (Barker, Neale, & Dingus, 1997).

Summary of Phase II

As previously explained, Phase I found that black on coral, black on light blue, and yellow on purple color combinations with a 125-mm (5-in) letter height, D series letters resulted in the best legibility distances. Phase II tested the three sign color combinations in addition to the standard black on orange sign color combination currently used for construction detours and emergency incident-related detours. The purpose of Phase II was to evaluate quantitatively the conspicuity of the experimental signs when overlaid with an existing construction detour.

Phase II was conducted using an instrumented vehicle through a construction zone-related detour. Questionnaire data were also obtained. The independent variables of interest were sign color combination, age, and visibility condition. The findings of Phase II indicated that use of a color combination other than the traditional black on orange sign would improve driver performance and safety when used for trailblazing during critical incidents. Conclusions were:

1. Yellow on purple or black on light blue will likely result in fewer late braking maneuvers if the road geometry has many tight curves.

2. Black on light blue will result in the fewest number of turn errors.

3. Black on orange will result in more turn errors, especially during the day and particularly when it is overlapped with existing detour/construction zone signs.

4. Black on coral is least preferred by older and younger drivers.

5. Younger drivers tend to prefer yellow on purple, and older drivers tend to prefer black on light blue.

It was also determined during the evaluation that the black on light blue sign fades to appear black on white when headlights illuminate the sign at night. For this reason, this sign was considered unusable for practical purposes, although the sign yielded favorable results. Based on the conclusions and the fact that fluorescent sign colors were not tested, the sign that showed the most promise for use as an incident management trailblazing sign was yellow on purple.

PURPOSE AND SCOPE: PHASE III

As previously stated, fluorescent colors were not evaluated in Phases I and II. This is a serious limitation considering that fluorescent signs are more efficient at converting incident daylight into sign luminance for the driver (Burns & Johnson, 1997). This fluorescent property results in improved visibility of fluorescent signs during daylight conditions (Burns &Pavelka, 1995; Zwahlen &Schnell, 1997). In addition, anecdotal evidence suggests that the use of fluorescent signs improves their conspicuity for incident management purposes. Therefore, the purpose of Phase III was to evaluate fluorescent colors. This included obtaining field data using full-size (0.610 m by 0.762 m, or 24 in by 30 in) test signs of the following colors:

1. black on fluorescent coral (also known as "hot pink")

2. fluorescent yellow on fluorescent purple

3. black on fluorescent yellow-green

4. yellow on purple in non-fluorescent colors (as a baseline such that comparisons may be made between the results of phase II and phase III).

A coral sign color was tested in Phase II without favorable results. Nonetheless, the fluorescent coral material creates different luminance and color properties that would make the use of the fluorescent coral material a viable option for incident management trailblazing. Regarding the fluorescent yellow-green material, a Notice of Amendment to the MUTCD published in the *Federal Register* (Federal Highway Administration, 1998) stated that the fluorescent yellow-green color is to be used for warning signs related to pedestrian, bicycle, and school applications. However, the Maryland State Highway Administration had approval to experiment using this color. Therefore, it was agreed that this color would be incorporated for testing during Phase III of the project for Maryland.

The driver response to the design parameters developed in Phase III was examined in terms of the following:

1. the conspicuity of the experimental sign color combinations relative to the traffic environment under normal traffic conditions, with respect to driver age and day and night visibility conditions

2. the readability of, understandability of, and overall preference for the experimental sign color combinations under normal traffic conditions with respect to driver age and day and night visibility conditions.

The primary goal of this research was to determine if there is improved conspicuity with fluorescent signing materials when compared to the non-fluorescent yellow on purple sign that was used in the Phase II study. The expected benefits of a modified detour sign design for incident management include improved safety as more visible and conspicuous signs will increase driver awareness of traffic direction information, regardless of visibility condition. In addition, it is expected that older drivers will benefit because of the age-related need for enhanced color contrast and brightness in traffic control signs.

METHODS AND MATERIALS

Experimental Design

To evaluate these sign colors, a 4 x 2 x 2 (Sign color x Age x Visibility condition) between factor design was used for the study. The general assignment of participants is shown in Table 1. Participants were randomly assigned between daytime and nighttime visibility conditions. Each participant was shown one test sign color combination and exposed to one viewing condition. The same experimental detour route and instrumented vehicle were used for all participants (see Appendix A for a map of the route and Appendix B for a description of the vehicle).

The 19.6 km (12.2 mi) route was blazed with one of the four test signs through urban and rural areas in Montgomery County, Virginia. Each sign was posted for 2 to 3 weeks during late winter and spring seasons. There were 23 sign locations.

Table 1. Experimental assignment of participants.

	Younger Drivers		Older Drivers		
Sign Color Combination	**Daytime**	**Nighttime**	**Daytime**	**Nighttime**	**Totals**
Yellow on Purple (Non-Fluorescent)	6	6	6	5	23
Black on Fluorescent Yellow-Green	5	6	4	5	20
Black on Fluorescent Coral	6	6	6	6	24
Fluorescent Yellow on Fluorescent Purple	6	6	6	6	24
Total	23	24	22	22	
	47		44		91

Independent Variables

- *Sign color combination:* The four experimental sign color combinations included black on fluorescent coral, fluorescent yellow on fluorescent purple, black on fluorescent yellow-green, and yellow on purple in non-fluorescent colors. The last sign color combination was tested as a baseline such that comparisons may be made between the results of Phase II and Phase III.

- *Age:* The two age groups of drivers used were younger drivers (18-34 years) and older drivers (55 and older years).

- *Visibility condition:* Participants drove during either day or night visibility conditions (a between-subjects variable). Daytime test sessions began no sooner than 1 hour after sunrise and no later than 1 hour before sunset. Furthermore, daytime viewing conditions included both clear conditions and cloudy or partly cloudy conditions. Nighttime test sessions began no sooner than one-half hour after sunset and were conducted with only the low-beam headlights of the test vehicle. All data collection occurred in fair weather (i.e., no precipitation).

Controlled Variables

- *Gender:* Gender was controlled such that an approximately equal number of male and female drivers were assigned and tested under daytime and nighttime conditions, respectively.

Dependent Variables

The in-vehicle data collection system provided the capability to store data on a computer in the form of one line of numerical data every 0.1 seconds during a data run. Vehicle data collection records were time-stamped to an accuracy of ±0.1 seconds. The specific measures collected were:

- *Late braking reaction:* A late reaction was operationally defined by a brake position more than two standard deviations from the mean brake position during the course of a sign event. A sign event began when a sign came into view as defined by the experimenter and ended when the experimental vehicle passed the sign.

- *Number of wrong and missed turns:* A wrong turn event was defined as a turn taken when no directional information was provided to indicate a required turn. A missed turn event was defined as a required turn that was not taken when indicated by a sign. In the event that a wrong turn and a missed turn occurred for the same sign site, only one error was counted. An experimenter in the vehicle collected these data.

- *Subjective acceptance and preference measures:* These data were collected via a post-test subjective questionnaire to assess the driver's impressions and preferences about the TEST DETOUR signs.

Participants

The intent was to have 96 participants to have six subjects per experimental cell. However, because of sign vandalism, 91 drivers participated in this study. Forty-seven participants were between the ages of 18 and 34 (younger drivers), and 44 participants were between the ages of 55 and 83 (older drivers). Approximately equal numbers of males and females participated. Drivers were recruited through flyers posted at local merchants in the Montgomery County area and on the Virginia Tech campus; announcements using senior citizen list serves; and contact with area churches and clubs. Drivers received $15 compensation for participating in the approximately 1-hour study.

Each participant was required (1) to be a licensed driver, (2) to drive a minimum of twice a week, (3) to pass a health-screening questionnaire, and (4) to have a minimum visual acuity of 20/40, wearing corrective lenses if necessary. In addition, participants were screened for color vision deficiencies.

Apparatus

The apparatus used in the study included (1) a vision tester, (2) an instrumented automobile, (3) the experimental signs, and (4) a post-drive questionnaire.

Titmus® II Vision Tester

This device was used to screen participants for visual acuity and color discrimination (i.e., color vision) at a far distance. The device included a Landholt broken ring test for visual acuity. The level of visual acuity was determined by the participant's ability to locate and identify the unbroken ring in each of the numbered targets. The color vision test consisted of six accurately reproduced Ishihara Pseudo-Isochromatic Plates. This test was used to identify the presence of a color deficiency, but it was not able to classify as to type. It should be noted that the reliability of the vision tester was suspect with regard to color vision; therefore, the color vision results did not affect driver assignment.

Automobile

A 1995 Oldsmobile Aurora was used as the experimental vehicle for all participants. The instrumentation in the vehicle provided the means to unobtrusively collect, record, and reduce a number of data items, including measures of attention demand, measures of navigation performance, safety-related incidents, and subjective opinions of the participants. The system consisted of video cameras to record pertinent data events, an experimenter control panel to record time and duration of events and information on an MS display, sensors for the detection of variations in driving performance and behavior, and a custom analog-to-digital interface and computer to log the data in the required format for analysis. A detailed description of the components of the vehicle can be found in Appendix B.

Experimental Signs

Manufacturing

The Culpeper District Sign Shop of the Virginia Department of Transportation (VDOT) manufactured each of the signs used in this study. The study focused on four sign color combinations: black on fluorescent yellow-green, black on fluorescent coral (hot pink), fluorescent yellow on fluorescent purple, and yellow on purple in non-fluorescent colors. Each test sign manufactured for this phase of the research was 0.610 m (24 in) by 0.762 m (30 in) and had 12.5-cm (5-in) Series D letters. The signs read "TEST" on the first line and " ROUTE" on the second line. Remaining specifications are shown in Figure 1. A photograph of the experimental sign color combinations is shown in Figure 2.

The test signs used 3M's Scotchlite Diamond Grade Visual Impact Performance (VIP) reflective sheeting. This sheeting was selected because of its ability to remain highly retroreflective when large observation angles exist and yet perform equally well at long distances. A large observation angle is usually created when a vehicle is within 60.96 m (200 ft) of a sign. This situation is typical of the driving conditions found in urbanized areas. The test route used in this research had a cross section of urbanized and rural driving conditions.

A description of the manufacturing process is given in Appendix C. None of the procedures used for sign manufacture was abnormal for the technicians in VDOT's sign shop. The fluorescent yellow-green sign material is commercially available. The fluorescent coral (hot pink) and fluorescent purple overlay films and the non-fluorescent purple inks that were provided by 3M were manufactured strictly for experimental use on this project and did not

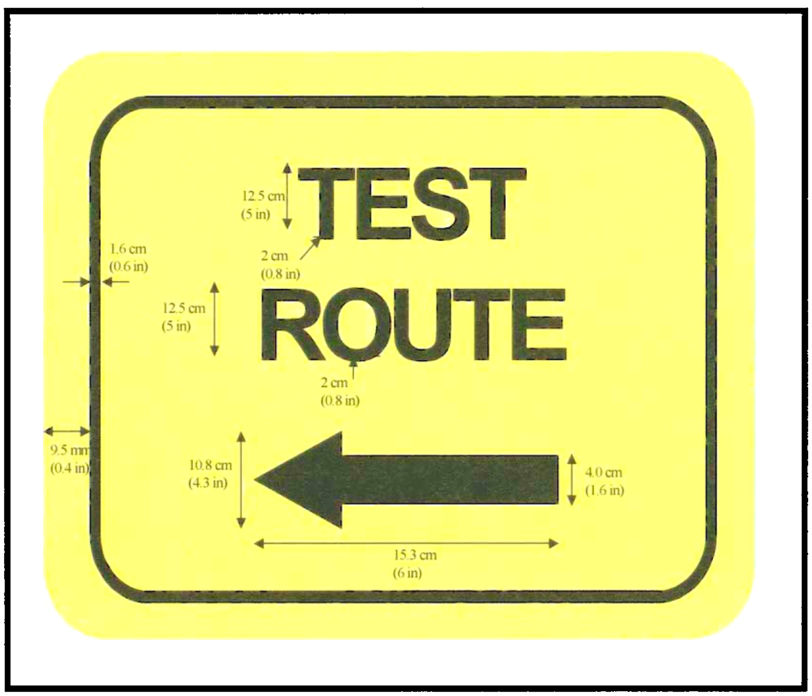

Figure 1. Experimental TEST DETOUR sign specification.

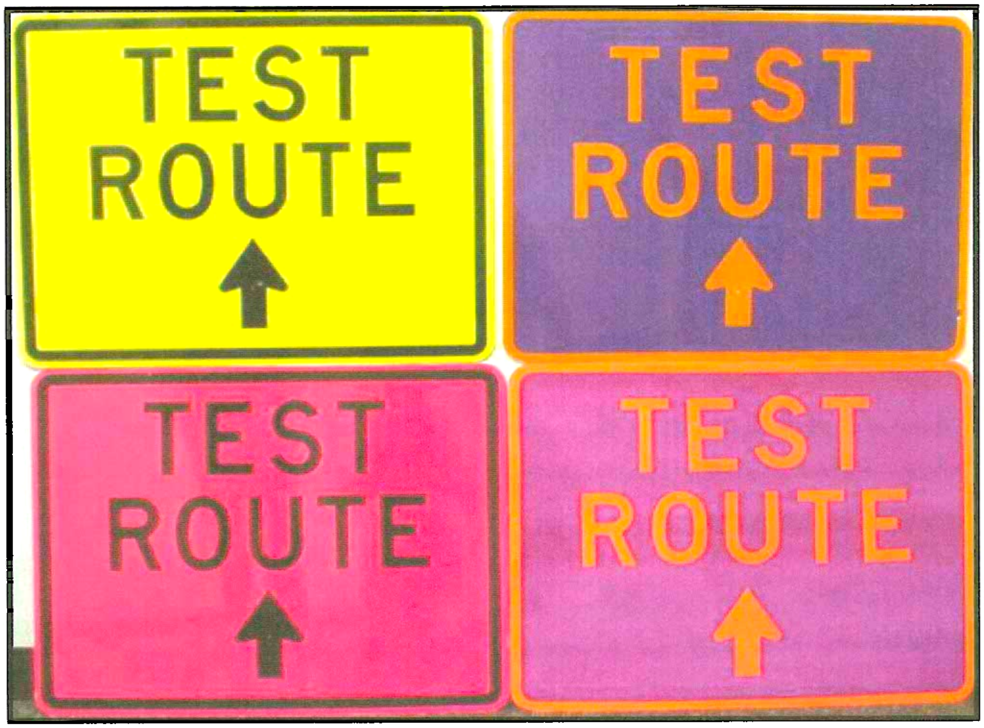

Figure 2. The experimental test signs (clockwise from the top left: black on fluorescent yellow-green, yellow on purple in non-fluorescent colors, fluorescent yellow on fluorescent purple, and black on fluorescent coral).

represent commercially available materials in terms of quality, handling characteristics, or color uniformity.

CIE Notation

Table 2 contains Commission International d'Eclairge (CIE) Notations and contrast ratios for the manufactured signs during conditions of simulated daylight. Appendix D contains a description of the equipment and procedures utilized in obtaining the values in Table 2.

Table 2. CIE notation and contrast ratios for experimental test signs.

Sign Color	CIE Y(%)	CIE x	CIE y	Contrast Ratio
Non-Fluorescent Purple Non-Fluorescent Yellow Arrow	8.30 46.7	.351 .539	.218 .454	5.6
Fluorescent Yellow-Green Black Arrow	137.0 1.72	.424	.563	79.7
Fluorescent Coral Black Arrow	43.2 1.63	.564	309	26.5
Fluorescent Purple Fluorescent Yellow Arrow	12.8 87.9	.480 .537	.233 .457	6.9

Sign Placement

Twenty-three experimental signs were posted along the route. To the extent possible, sign were supported on standard signposts. Exceptions were sign panels that, because of the urban location constraints, were mounted on existing posts (light, utility, etc.). Each sign panel was oriented approximately perpendicular to the direction of travel, facing the observation vehicle, as is normal practice. Sign supports were located on the right shoulder of the road in all but three locations. Deviations from the MUTCD specifications were due to requirements to be compliant with existing traffic sign locations at those sites.

Post-test Questionnaire

The post-test questionnaire used to gather subjective opinion data is shown in Appendix E. The first three questions asked drivers to *rate* the sign they had just seen on the test route in terms of visibility, ease of identifying and understanding the directional information, and usefulness of the sign information. These questions asked drivers to make a relative judgment of the sign they had seen on the test route; that is, the drivers had seen only one sign color to this point and could not judge the sign color as it compared with the other sign colors.

Questions 4, 5, and 6 asked drivers to *rank* the four sign colors based on viewing 16.5-cm x 29.2-cm (6.5-in x 11.5-in) samples of the sign material. Drivers were asked to rank the signs in terms of visibility, readability, and overall preference. This was the first opportunity the drivers had to see all four sign colors. The drivers did not have the opportunity to see the signs with varying levels of daytime light, such as might occur with a changing sun position, or during nighttime viewing conditions, in which case the effect of headlights could dramatically change the appearance of the signs. However, questions 4, 5, and 6 did allow for an absolute judgment of sign colors; that is, the drivers could look at the four sign colors together and decide which they most and least preferred.

Procedure

Participants were initially screened over the telephone regarding age, gender, driving frequency, and general health. If determined to be eligible, participants were scheduled for testing. Participants were instructed to meet experimenters at the Virginia Tech Transportation Institute (VTTI) in Blacksburg, Virginia. Upon arrival, participants were given an overview of the study and were asked to review and complete the informed consent form (Appendix F). Next, they were asked to complete the health-screening process (i.e., complete part 2 of the questionnaire) (Appendix G). Following this, a vision test was administered using the Titmus® II vision tester. Participants were then escorted to the test vehicle. The vehicle's windshield was cleaned prior to each testing session. While the car was in park, the experimenter reviewed general information concerning the operation of the test vehicle (e.g., lights, seat adjustment, mirrors, and windshield wipers). Participants were asked to operate each control and set it for their driving comfort. When the participants felt comfortable with the controls, the experimenter briefly described the driving task. Participants had to maneuver the test vehicle through several turns to get out of the VTTI facility. If the drivers indicated that they felt comfortable with the car, the test began.

The experimental protocol required two experimenters and the participant to be in the vehicle. The experimenter seated in the front passenger seat gave initial navigational instructions, served as the safety officer, flagged events in the data set using the event flagger, and recorded the events corresponding to the flagged data on a data sheet. Only unplanned external events, such as a preceding car slowing suddenly, were flagged during the data collection session; the "planned" sign events were marked manually during later data analysis. The second experimenter was seated in the back seat and monitored the data collection computer. The low-beam halogen headlights were used during nighttime driving conditions.

At the beginning of the test route, participants were instructed to look for and follow the signs that read TEST ROUTE (the sign color was not mentioned). Participants were also instructed that all test signs would contain the same text legend and that each sign would contain a directional arrow to indicate the route to be followed. While following the directions provided by the signs, participants were instructed to obey the traffic laws and to drive safely. If a wrong turn was made, the experimenter allowed the driver to complete the turn and then immediately directed him or her back to the prescribed route.

The study was conducted in Montgomery County, Virginia, along both urban and rural roadways (Appendix A). The route began at the intersection of Transportation Research Drive and Industrial Park Road in Blacksburg and then proceeded along U.S. Business Route 460 to downtown Blacksburg. After a series of three turns, the route proceeded out of town on East Roanoke Street and Harding Avenue. The route then followed Route 723 to Route 1260 and returned to Blacksburg on Route 681.

The test route was approximately 19.6 km (12.2 mi) long. The roadways along the test route were both two-lane and four-lane roads with marked lanes. Some rural sections of the route outside the Blacksburg town limits had few sources of illumination other than occasional private homes or businesses. Following completion of the test route, participants drove back to VTTI and completed the post-drive questionnaire (see Appendix E). Participants were then debriefed and compensated for their time. The total time for the experiment averaged 1 hour.

RESULTS AND DISCUSSION

To interpret the driving performance and subjective results obtained accurately, it was necessary to make daytime and nighttime photometric measurements of the test signs. This section presents the results of the study in four main sections: Daytime Photometric Measurements, Nighttime Photometric Measurements, Driving Performance Variables, and Driver Preference Data.

Daytime Photometric Measurements

Personnel at 3M took readings of sign material samples in the laboratory and in the field under full sun and full shade (Table 3). Each sign's total luminance factor (Y) and fluorescence luminance factor (Y_F) values were measured using a Labsphere® BFC-450 Bispectral Fluorescence Colorimeter. Field measurements of each sign's background luminance under ambient daytime conditions were made using a Photo Research® PR-650 telespectroradiometer.

For both ambient conditions, full sun and full shade, measurements were made of a white Spectralon™ UV-VIS-NIR Diffuse Reflectance Target SRT-99 mounted next to the test signs. The Spectralon SRT-99 is essentially a perfect diffuse reflector (PDR) having spectral reflectances of greater than 98 percent from 300 nm to 800 nm. The PDR value represents the maximum luminance possible from a reflecting surface. For both ambient conditions, full sun and full shade, the average correlated color temperatures (CCT) are provided. Y_F is a laboratory measurement, and Y_{field} is a field measurement calculated by taking the ratio of the luminances. The field luminance factors (Y_{field}) for each test sign's background and legend were calculated by taking the ratio of the sign's luminance value to the PDR luminance value.

As Table 3 shows, the field luminance factors remain relatively constant from the full sun condition to the full shade condition. For the most part, the field luminance factors are higher than the total luminance factors obtained in the laboratory. What is obvious is that the fluorescent yellow-green color produced consistently higher luminance and Y_{field} factors than the other three background colors tested for both ambient conditions. The next highest value was the fluorescent coral material; however, this color provided only 38.7 percent of the luminance the fluorescent yellow-green background provided in full sun and 23.6 percent in the full shade condition. Both purple backgrounds provided significantly less luminance than the fluorescent yellow-green and fluorescent coral backgrounds. The fluorescent purple background provided minimal increases in luminance over the non-fluorescent purple material. The fluorescent yellow-green material provided more luminance than the PDR under the full shade condition because of the emissions provided by the fluorescent chemicals.

Table 3. Laboratory and field luminance measurement results.

Sign Color	Laboratory CIE D_{65}		Field-Full Sun CCT 5125 K		Field – Full Shade CCT 6306 K	
	Y (%)	Y_F (%)	cd/m^2	Y_{field} (%)	cd/m^2	Y_{field} (%)
SRT-99 (PDR)	-	-	23,150	100	3,384	100
Non-Fluorescent Purple	4.04	0	1,858	8.0	189	5.6
Non-Fluorescent Yellow*	34.67	0	9,144	39.5	1,303	38.5
Fluorescent Purple	6.18	3.42	2,137	9.2	341	10.1
Fluorescent Yellow*	50.39	32.54	13,100	56.6	2,171	64.2
Fluorescent Yellow-Green	83.98	46.88	16,700	72.1	3,934	116.3
Black*	4.00	0	173	0.7	29	0.9
Fluorescent Coral	19.69	11.01	6,455	27.9	929	27.5
Black*	4.00	0	173	0.7	29	0.9

* Legend color.

In an effort to foster a better understanding of daytime legibility and driver preferences, luminance contrast ratios (legend to background) for each test sign were calculated for each ambient viewing condition (Table 4). As expected, the black on fluorescent yellow-green sign provided the highest contrast: 1:97 to almost 1:135. The black on fluorescent coral test sign had the second highest contrast ratios at 1:32. The purple test signs provided the lowest luminance contrast ratios under both viewing conditions, ranging from almost 5:1 to as high as almost 7:1.

Table 4. Experimental sign contrast ratios.*

Test Sign	Full Sun Condition	Full Shade Condition
Yellow on Purple (Non-fluorescent)	4.9 : 1	6.9 : 1
Black on Fluorescent Yellow-Green	1 : 96.5	1 : 135.7
Black on Fluorescent Coral	1 : 37.3	1 : 32.0
Fluorescent Yellow on Fluorescent Purple	6.1 : 1	6.4 : 1

* Calculated legend to background.

Nighttime Photometric Measurements

Nighttime photometric measurements were taken to quantify the difference in luminance among the four sign color combinations under a headlight illumination. Measurements were made with a LMT photometer positioned between the headlights of a 1997 Ford Taurus. The vehicle was located 85.3 m (280 ft) from the signs, which were mounted at a height of 1.5 m (5 ft) above the surface of the road and 1.8 m (6 ft) from the edgeline to the nearest edge of the sign. The signs were placed perpendicular to the roadway and upright (i.e., no twist, tilt, or rotation). The photometer was set 1.1 m (3.5 ft) above the pavement in line with the driver's eye. The corresponding entrance and observation angles calculated for this geometry, to the center of the signs, were 2.82 and 0.52 degrees, respectively. For each sign, three luminance measurements were made in four areas of the background: upper left corner, upper right corner, lower right corner, and lower left corner. A luminance measurement of the directional arrow was also made to determine the contrast between the legend and background. In addition, illuminance measurements were made at the sign face in the same areas in which the luminance measurements were made. Table 5 provides the mean measurement values for each sign.

Table 5. Mean nighttime retroreflectivity, illuminance, luminance, and contrast ratios for the experimental test signs.

Sign Color	Retroreflectivity (cd/lx/m²)	Illuminance (lx)	Luminance (cd/m²)	Contrast Ratio
Non-Fluorescent Purple	123.8	1.15	83.07	1.8:1
Non-Fluorescent Yellow*	400	–	152.0	
Fluorescent Yellow-Green	427.8	1.31	380.5	1:1.7
Black*	0.5	–	219.0	
Fluorescent Coral	131.3	1.31	78.52	1:1.8
Black*	0.5	–	43.0	
Fluorescent Purple	41.8	1.26	42.98	2.7:1
Fluorescent Yellow *	303	–	115	

* Legend color.

Overall, the fluorescent yellow-green color provided the highest luminance and retroreflectivity for its background: more than 4.5 times that of the next brightest sign (non-fluorescent purple) and almost 9 times that of the fluorescent purple sign with the lowest luminance of all four signs. The luminance of the black legends was higher than expected. This could be due to the overwhelming brightness of the backgrounds of the fluorescent yellow-green and fluorescent coral signs. Both signs tended to exhibit a halation effect around the legend areas that, in turn, increased the luminance of the legend thereby decreasing the contrast ratio. The fluorescent coral and fluorescent purple sign materials were laboratory developed, non-production quality overlay films and were thicker than typical production material. As such, the resulting nighttime luminance values were likely lower than would be expected after full-scale production.

Driving Performance Variables

Statistical analyses were conducted using the SAS® 6.12 software package. As is typical of field experiments, some data cells were not filled. Therefore, all analyses of variance (ANOVAs) were performed by running a general linear model (GLM) procedure. The traditional ANOVA procedure is designed for use on balanced data sets. For this experiment, an 0.05 significance level was used (95 percent probability that the reported results reflect actual differences). Non-parametric tests were performed where appropriate.

Late Braking Maneuvers

A late braking maneuver was operationally defined as an incident requiring a brake pedal depression that exceeded two standard deviations from the mean brake position to slow to make a turn during the course of a sign event. A sign event began when a sign came into view as defined by the experimenter and ended when the experimental vehicle passed the sign.

Only one sign event, shown in Appendix A as site number 18, had enough late braking maneuvers to evaluate (one other sign event resulted in one late braking maneuver). The roadway at site 18 was such that the driver, traveling at 45 mph, was required to make a right turn onto a secondary route. It is hypothesized that the the sign arrow was too small for the driver to determine direction in adequate time considering the rate of travel.

Seventeen of 82 drivers demonstrated late braking reactions at site 18 (Table 6). Because of the small frequencies in each cell, a proper application of the chi-square test could not be performed. The occurrences of late braking were distributed over the four sign colors in a manner resulting in little difference among the signs. It is noteworthy that 14 of the 17 late braking maneuvers were attributed to drivers in the older category, with the fewest of those being for the black on fluorescent yellow-green sign (Table 7). Also of interest is the fact that 13 of the 17 late braking maneuvers occurred during conditions of darkness, with no late braking maneuvers occurring during daytime conditions with the black on fluorescent yellow-green sign (Table 8).

Table 6. Frequency of late braking maneuvers at sign 18.

Sign Color Combination	No Late Reaction Observed	Late Reaction Observed
Yellow on Purple (Non-Fluorescent)	18	3
Black on Fluorescent Yellow-Green	16	4
Black on Fluorescent Coral	15	5
Fluorescent Yellow on Fluorescent Purple	16	5

Table 7. Frequency of late braking maneuvers by age and sign color combination.

Sign Color Combination	Older Drivers	Younger Drivers
Yellow on Purple (Non-Fluorescent)	3	0
Black on Fluorescent Yellow-Green	2	2
Black on Fluorescent Coral	4	1
Fluorescent Yellow on Fluorescent Purple	5	0

Table 8. Frequency of late braking maneuvers by visibility and sign color combination.

Sign Color Combination	Daytime	Nighttime
Yellow on Purple (Non-Fluorescent)	1	2
Black on Fluorescent Yellow-Green	0	4
Black on Fluorescent Coral	2	3
Fluorescent Yellow on Fluorescent Purple	1	4

Anecdotally, the black on fluorescent yellow-green sign was visible at a great distance during the day. The comparatively high daytime luminance values of the black on fluorescent yellow-green sign (Table 3) are likely to be a contributing factor for the daytime results. Regarding the nighttime results, many participants commented that the directional arrow on the signs were too small to identify the directional information until they were fairly close to the sign. Several participants noted that they saw the sign but did not realize that a turn was indicated until they were fairly close to the sign; thereby warranting a late braking maneuver. This result is likely related to the nighttime luminance of the black legends for the fluorescent yellow-green and fluorescent coral signs. Recall that these signs exhibited a halation around the legend areas. This effect increased the luminance of the legend and decreased the contrast ratio, which resulted in the directional arrow appearing smaller.

In general, there were not enough occurrences of late braking maneuvers to allow for a test of significant differences. Therefore, based on the late braking results, one could construe that the four sign color combinations were equally conspicuous.

Analysis of Wrong and Missed Turns

Wrong and missed turns were consolidated and analyzed together as turn errors. A *wrong turn event* was defined as a turn taken when no directional information was provided to indicate a required turn. A *missed turn event* was defined as a required turn that was not taken when indicated by a sign. In the event that a wrong turn and a missed turn occurred for the same sign event, only one error was counted. For all analyses of wrong and missed turns, the expected frequencies were too small for a proper application of the chi-square test.

Table 9 shows the frequency of correct turns and turn errors listed by sign color. Only nine turn errors were committed of 2,082 opportunities to make a turn error (0.004 %). Table 10 shows the frequency of turn errors by driver age and sign color combination. The majority of errors made by younger drivers occurred with the fluorescent yellow on fluorescent purple sign, and the majority of errors made by older drivers occurred with the black on fluorescent coral sign. Table 11 shows the frequency of turn errors by visibility condition for each sign color combination. As expected, the majority of turn errors occurred at nighttime.

Recall that many participants commented that the turn arrows on the signs were too small to identify the directional information until they were fairly close to the sign. Participants noted that the signs were conspicuous and could be detected from an acceptable distance, but the

Table 9. Overall frequency of turn errors by sign color combination.

Sign Color Combination	Correct Turns	Incorrect Turns
Yellow on Purple (Non-Fluorescent)	517	1
Black on Fluorescent Yellow-Green	459	1
Black on Fluorescent Coral	548	4
Fluorescent Yellow on Fluorescent Purple	549	3

Table 10. Frequency of turn errors by driver age and sign color combination.

Sign Color Combination	Younger Drivers	Older Drivers
Yellow on Purple (Non-Fluorescent)	0	1
Black on Fluorescent Yellow-Green	0	1
Black on Fluorescent Coral	1	3
Fluorescent Yellow on Fluorescent Purple	3	0

Table 11. Frequency of turn errors by visibility condition and sign color combination.

Sign Color Combination	Daytime	Nighttime
Yellow on Purple (Non-Fluorescent)	0	1
Black on Fluorescent Yellow-Green	0	1
Black on Fluorescent Coral	1	3
Fluorescent Yellow on Fluorescent Purple	1	2

arrows, because of their size, necessitated a closer approach to ascertain the directional information. It may be that since the signs were visible and conspicuous from such great distances, the drivers wanted to see the directional information sooner. Nonetheless, there were very few (0.004 %) wrong and missed turns, again indicating that the signs were equally conspicuous.

Driver Preference Data

For questions 1, 2, and 3, the participants rated only the sign they saw while driving (refer to the section "Post-test Questionnaire" and Appendix E). The numbers of participants who viewed each sign color were unequal; therefore, the numbers of drivers rating each sign were unequal.

Question 1: How Visible Was the Test Detour Sign Relative to the Environment?

This question asked participants to rate the visibility of the experimental sign they had seen on the test route using a Likert-type scale of 1 to 5, with 1 meaning not visible and 5 meaning extremely visible (see Appendix E). ANOVAs were performed on the mean ratings for this question. Results of this analysis can be found in Appendix H, Table H-1.

An analysis for sign color revealed that the ratings were significantly different (Table 12). Drivers who saw the black on fluorescent yellow-green and black on fluorescent coral signs thought the experimental sign they had seen was very to extremely visible. Drivers in both the fluorescent and non-fluorescent yellow on purple groups rated the experimental sign they had seen as moderately to very visible. A Tukey pairwise comparison (Figure 3) revealed that the black on fluorescent yellow-green and black on fluorescent coral signs were rated as significantly more visible than the non-fluorescent yellow on purple sign. The fluorescent yellow on fluorescent purple sign was not rated significantly different from the other three signs. Significant differences are indicated by different letters. If two levels of the variable share the same letter, they are not significantly different.

Table 12. Survey question 1 mean ratings for assessment by sign color.

Sign Color Combination	Mean*/STD (Number)	Significance Level for Sign Color
Yellow on Purple (Non-Fluorescent)	3.65/0.63 (N=23)	$F(3,75) = 6.73$, $p = 0.0004$
Black on Fluorescent Yellow-Green	4.43/0.48 (N=20)	
Black on Fluorescent Coral	4.25/0.72 (N=24)	
Fluorescent Yellow on Fluorescent Purple	3.96/0.61 (N=24)	

* 1 = not visible, 5 = extremely visible.

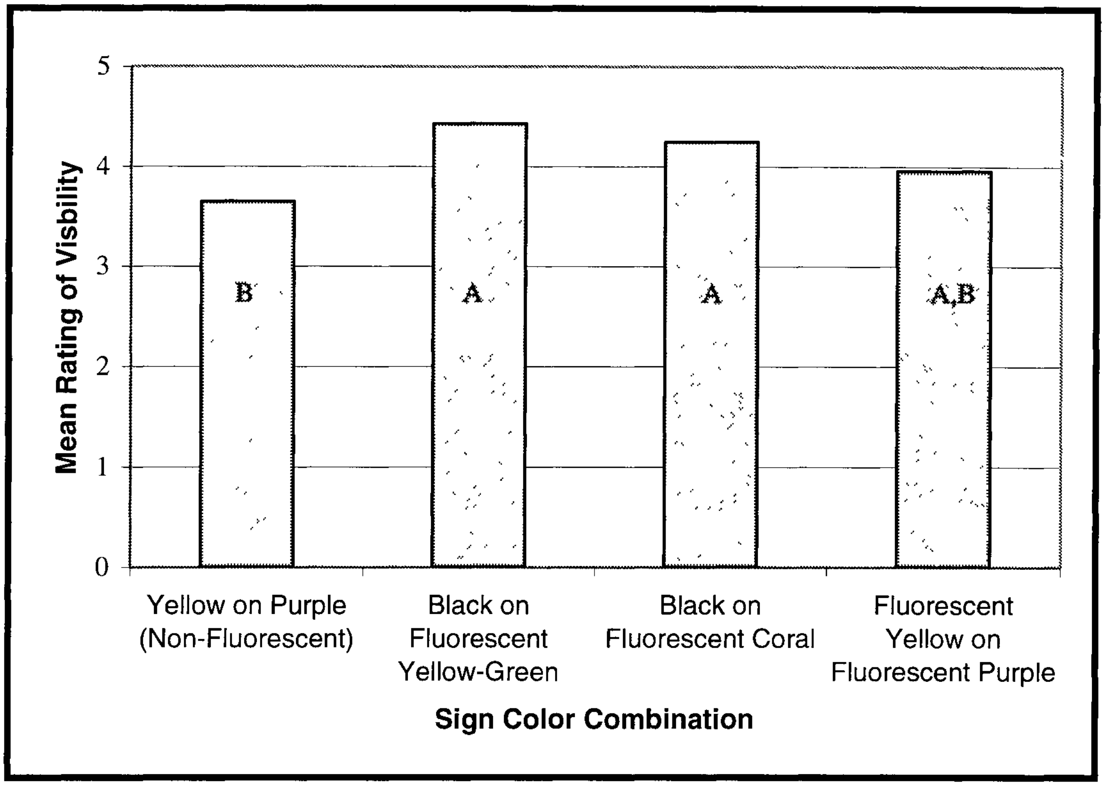

Figure 3. Results of Tukey pairwise comparison for question 1.

For the assessment by age, the mean ratings for older and younger drivers are shown in Table 13. ANOVA for age-related differences revealed that the ratings by younger and older drivers were not significantly different for each sign color. Both younger and older drivers thought that the experimental sign they saw was moderately to very visible.

Table 13. Question 1 mean ratings for assessment by age.

Sign Color Combination	Younger Mean/STD (Number)	Older Mean/STD (Number)	Significance Level for Age Condition
Yellow on Purple (Non-Fluorescent)	3.67/0.62 (N=12)	3.64/0.64 (N=11)	$F(1,75) = 0.79$, $p = 0.3779$
Black on Fluorescent Yellow-Green	4.50/0.48 (N=11)	4.33/0.47 (N=9)	
Black on Fluorescent Coral	4.33/0.94 (N=12)	4.17/0.37 (N=12)	
Fluorescent Yellow on Fluorescent Purple	4.00/0.82 (N=12)	3.92/0.28 (N=12)	

* 1 = not visible, 5 = extremely visible.

For the assessment by visibility condition, the mean ratings for daytime and nighttime drivers are shown in Table 14. ANOVA for differences in ratings between daytime and nighttime drivers revealed no significant differences. The mean rating for daytime drivers was 4.14, and that for nighttime drivers was 3.98, indicating that the daytime and nighttime drivers thought the signs were very visible.

Table 14. Question 1 mean ratings for assessment by visibility condition.

Sign Color Combination	Daytime Mean/STD (Number)	Nighttime Mean/STD (Number)	Significance Level for Visibility Condition
Yellow on Purple (Non-Fluorescent)	3.58/0.49 (N=12)	3.73/0.75 (N=11)	F (1,75) = 2.31, p = 0.1325
Black on Fluorescent Yellow-Green	4.61/0.46 (N=9)	4.27/0.45 (N=11)	
Black on Fluorescent Coral	4.58/0.49 (N=12)	3.92/0.76 (N=12)	
Fluorescent Yellow on Fluorescent Purple	3.92/0.49 (N=12)	4.00/0.71 (N=12)	

* 1 = not visible, 5 = extremely visible.

Question 2: How Easy Was It to Identify, or Understand, the Directional Information Provided by the Test Signs?

This question asked participants to rate the directional information on the experimental TEST ROUTE sign that they had seen while driving. The Likert-type rating scale ranged from 1 to 5, with 1 meaning not easy to identify and 5 meaning extremely easy to identify (see Appendix E). ANOVA was performed on the mean ratings for this question. The results are provided in Appendix H, Table H-2.

There was a significant sign by visibility condition interaction (Table 15). Results of a Tukey post-hoc analysis revealed a significant difference in mean ratings by daytime and nighttime drivers who observed the black on fluorescent coral sign. Nighttime drivers rated the directional information of the black on fluorescent coral sign as somewhat to moderately easy to identify, and daytime drivers rated the directional information as moderately to very easy to identify. This may be attributable in part to the halation effect that occurs for the black on fluorescent coral sign during nighttime viewing conditions resulting in a decreased contrast ratio, as discussed earlier. Mean ratings by daytime and nighttime drivers were not significantly different with the other sign color combinations, which is further indicated by the non-significant main effect of visibility condition (Appendix H, Table H-2).

Table 15. Question 2 mean ratings for sign color by visibility condition.

Sign Color Combination	Daytime Mean/STD (Number)	Nighttime Mean/STD (Number)	Significance Level for Sign Color by Visibility Interaction
Yellow on Purple (Non-Fluorescent)	2.75/1.16 (N=12)	3.45/0.99 (N=11)	F (3,75) = 3.50, p = 0.0195
Black on Fluorescent Yellow-Green	4.11/0.74 (N=9)	3.55/0.66 (N=11)	
Black on Fluorescent Coral	3.75/0.83 (N=12)	2.58/0.95 (N=12)	
Fluorescent Yellow on Fluorescent Purple	3.50/1.26 (N=12)	3.58/1.32 (N=12)	

* 1 = not easy, 5 = extremely easy.

The analysis of mean scores for sign color is shown in Table 16. The analysis for sign color was not significantly different. The trend suggests slightly higher ratings for the directional information on the black on fluorescent yellow-green sign and lower ratings for directional information on the non-fluorescent yellow on purple and black on fluorescent coral signs. Based on the mean ratings, participants thought the directional information for the sign that they had seen was moderately easy to identify or understand.

Table 16. Question 2 mean ratings for assessment by sign color.

Sign Color Combination	Mean*/STD (Number)	Significance Level for Sign Color
Yellow on Purple (Non-Fluorescent)	3.09/1.14 (N=23)	F(3,75) = 2.36, p = 0.0783
Black on Fluorescent Yellow-Green	3.80/0.75 (N=20)	
Black on Fluorescent Coral	3.17/1.07 (N=24)	
Fluorescent Yellow on Fluorescent Purple	3.54/1.29 (N=24)	

*1 = not easy, 5 = extremely easy.

An analysis for age differences revealed that the ratings by younger and older drivers were significantly different. The results indicate that older drivers rated the directional information significantly easier to identify and understand than did younger drivers. Table 17 shows the mean ratings for each sign by age group. Based on these ratings, younger drivers tended to rate the directional information moderately easy to identify and older drivers thought that the directional information was very easy to identify. This result is somewhat surprising in light of the fact that older drivers tend to have more difficulty reading road signs than do younger drivers. Perhaps the older drivers were responding to the increased detectability distance of the signs, which would have given them a greater distance from which to try and read the directional information on the signs.

Table 17. Question 2 mean ratings for assessment by age.

Sign Color Combinations	Younger Mean/STD (Number)	Older Mean/STD (Number)	Significance Level for Age Condition
Yellow on Purple (Non-Fluorescent)	2.67/0.94 (N=12)	3.55/1.16 (N=11)	F(1,75) = 7.35, p = 0. 0083
Black on Fluorescent Yellow-Green	3.45/0.78 (N=11)	4.22/0.42 (N=9)	
Black on Fluorescent Coral	3.00/1.08 (N=12)	3.33/1.03 (N=12)	
Fluorescent Yellow on Fluorescent Purple	3.33/1.18 (N=12)	3.75/1.36 (N=12)	

* 1 = not easy, 5 = extremely easy.

Question 3: How Useful Would You Find This Type of Sign Design for Providing Temporary Directional/Detour Information While Driving?

This question referred to the experimental TEST ROUTE sign that participants had seen on the test route (see Appendix E). Drivers were asked to rate the sign they had seen using a Likert-type scale of 1 to 5, with 1 meaning the information was not useful and 5 meaning the information was extremely useful. ANOVAs were performed on the mean ratings for this question. Results of this analysis can be found in Appendix H, Table H-3.

Table 18 shows the results of an analysis for sign color. The analysis for sign color was not significantly different. The trend suggests higher ratings for the black on fluorescent yellow-green sign (very to extremely useful) and lower ratings for the non-fluorescent yellow on purple sign (moderately to very useful).

An analysis by age group revealed that the ratings by younger and older drivers were not significantly different for each sign color. Based on the mean ratings by each group (Table 19), both younger and older drivers thought that the experimental sign they saw was moderately to very useful for providing detour information.

Table 18. Question 3 mean ratings for assessment by sign color.

Sign Color Combination	Mean*/STD	Significance Level for Sign Color
Yellow on Purple (Non-Fluorescent)	3.43/1.21 (N=23)	F(3,75) = 2.42, p = 0.0727
Black on Fluorescent Yellow-Green	4.25/0.70 (N=20)	
Black on Fluorescent Coral	3.75/0.88 (N=24)	
Fluorescent Yellow on Fluorescent Purple	3.67/1.18 (N=24)	

* 1 = not useful, 5 = extremely useful.

Table 19. Question 3 mean ratings for assessment by age.

Sign Color Combination	Younger Mean/STD (Number)	Older Mean/STD (Number)	Significance Level for Age Condition
Yellow on Purple (Non-Fluorescent)	3.33/1.11 (N=12)	3.55/1.30 (N=11)	F(1,75) = 1.81, p = 0.1828
Black on Fluorescent Yellow-Green	4.18/0.83 (N=11)	4.33/0.47 (N=9)	
Black on Fluorescent Coral	3.42/0.95 (N=12)	4.08/0.64 (N=12)	
Fluorescent Yellow on Fluorescent Purple	3.58/1.19 (N=12)	3.75/1.16 (N=12)	

* 1 = not useful, 5 = extremely useful.

An analysis by visibility condition revealed that the ratings were not significantly different for daytime drivers than for nighttime drivers. Both daytime and nighttime drivers found the signs moderately to very useful for detour information. Table 20 shows the mean ratings for each sign by visibility condition.

Table 20. Question 3 mean ratings for assessment by visibility condition.

Sign Color Combination	Daytime Mean/STD (Number)	Nighttime Mean/STD (Number)	Significance Level for Visibility Condition
Yellow on Purple (Non-Fluorescent)	3.17/1.07 (N=12)	3.73/1.29 (N=11)	F(1,75) = 1.25, p = 0.2674
Black on Fluorescent Yellow-Green	4.56/0.50 (N=9)	4.00/0.74 (N=11)	
Black on Fluorescent Coral	4.17/0.69 (N=12)	3.33/0.85 (N=12)	
Fluorescent Yellow on Fluorescent Purple	3.75/1.01 (N=12)	3.58/1.32 (N=12)	

* 1 = not useful, 5 = extremely useful.

Question 4: Rank the Sample Signs in Order of Preference for Visibility Along the Roadway, by Sign Color.

For question 4, drivers were shown sign color samples and photos of all four "TEST DETOUR" sign color combinations taken during daylight viewing conditions and were asked to rank them in order of preference for visibility along the roadway. For the purposes of analysis, the most preferred sign for visibility was equated to a numerical value of 1, and the least preferred sign was equated to a numerical value of 4. A Freidman two-way analysis of variance by ranks was used to analyze the data. Results of this analysis are shown in Appendix H, Table H-4.

An analysis to determine if the drivers ranked the sign colors differently was significant. Table 21 shows the rank sums for each sign. Pairwise comparisons revealed that all signs were ranked as significantly different from all other signs. The black on fluorescent yellow-green sign was ranked the most visible, followed by the black on fluorescent coral and fluorescent yellow on fluorescent purple signs. The non-fluorescent yellow on purple sign was ranked as the least visible sign.

An analysis by age group was conducted to determine if there was a significant difference in rankings of visibility between the younger and older drivers (Table 22). The mean results did not differ significantly; indicating that younger and older drivers ranked the signs similarly.

Table 21. Question 4 rank sum values for assessment by sign color.

Sign Color Combination	Rank Sum*	Analysis by Sign Color
Yellow on Purple (Non-Fluorescent)	344	$F_r(3,N=91)=202.71>$ $F_{tab}(alpha=0.05,df=3)=7.82$, $p< 0.001$
Black on Fluorescent Yellow-Green	108	
Black on Fluorescent Coral	191	
Fluorescent Yellow on Fluorescent Purple	267	

*Low number means higher ranking.

Table 22. Survey question 4 mean rankings for assessment by age.

Sign Color Combination	Younger	Older	Analysis by Age
Yellow on Purple (Non-Fluorescent)	3.8	3.7	$F_r(3,N=2)=6.0<$ $F_{tab}(alpha=0.05,df=3)=7.82$
Black on Fluorescent Yellow-Green	1.2	1.2	
Black on Fluorescent Coral	1.9	2.3	
Fluorescent Yellow on Fluorescent Purple	3.0	2.8	

*1 = most visible, 4 = least visible.

Question 5: Rank the Sample Signs in Order of Preference Based on How Easy You Feel the Signs Are to Read.

As with question 4, drivers were shown sign color samples of the four TEST ROUTE sign color combinations and asked to rank them in order of preference regarding readability (see Appendix E). Again, the most preferred sign was equated to a numerical value of 1, and the least preferred sign was equated to a numerical value of 4. ANOVA by ranks to determine if the drivers ranked the sign colors differently was significant. Table 23 shows the rank sums for each sign. Pairwise comparisons (see Appendix H, Table H-5) revealed that all signs were ranked significantly different from one another except the black on fluorescent coral sign versus the

Table 23. Question 5 rank sum values for assessment by sign color.

Sign Color Combination	Rank Sum*	Analysis by Sign Color
Yellow on Purple (Non-Fluorescent)	333	$F_r(3,N=91)=168.55>$ $F_{tab}(alpha=0.05,df=3)=7.82$, $p < 0.001$
Black on Fluorescent Yellow-Green	111	
Black on Fluorescent Coral	213	
Fluorescent Yellow on Fluorescent Purple	253	

*Low number means higher ranking.

fluorescent yellow on fluorescent purple sign. The black on fluorescent yellow-green sign was ranked most preferred for readability and the non-fluorescent yellow on purple sign was the least preferred.

An analysis was conducted to determine if there was a difference between rankings given by younger and older drivers (Table 24). The result was not significant, indicating that younger and older drivers did not rank the readability of each sign color sample differently.

Table 24. Question 5 mean rankings for assessment by age.

Sign Color Combination	Younger	Older	Analysis by Age
Yellow on Purple (Non-Fluorescent)	3.6	3.7	$F_r(3,N=2)=6.0<$ $F_{tab}(alpha=0.05,df=3)=7.82$
Black on Fluorescent Yellow-Green	1.2	1.2	
Black on Fluorescent Coral	2.3	2.4	
Fluorescent Yellow on Fluorescent Purple	2.8	2.7	

*1 = most easy to read, 4 = least easy to read.

Question 6: Rank the Sample Signs in Order of Overall Preference for Use on Signs Providing Temporary Directional/Detour Information.

For this question, drivers were shown sign color samples of the four TEST ROUTE sign color combinations. The participants were then asked to rank the signs in order of overall preference for providing temporary directional/detour information. Again, the most preferred sign was equated to a numerical value of 1, and the least preferred sign was equated to a numerical value of 4. A Friedman two-way analysis of variance by ranks was used to analyze the data. Results of this analysis are shown in Appendix H, Table H-6.

An analysis to determine if the drivers ranked the sign colors differently was significant. Table 25 shows the rank sums for each sign. Pairwise comparisons revealed that all signs were ranked significantly different from each other. The most preferred sign was for providing temporary directional/detour information was the black on fluorescent yellow-green sign followed by the black on fluorescent coral and fluorescent yellow on fluorescent purple signs. The non-fluorescent yellow on purple sign was ranked least favorably.

Table 25. Question 6 rank sum values for assessment by sign color.

Sign Color Combination	Rank Sum*	Analysis by Sign Color
Yellow on Purple (Non-Fluorescent)	338	$F_r(3,N=91)=165.42>$ $F_{tab}(alpha=0.05,df=3)=7.82$, $p < 0.001$
Black on Fluorescent Yellow-Green	119	
Black on Fluorescent Coral	203	
Fluorescent Yellow on Fluorescent Purple	250	

*Low number means higher ranking.

An analysis was also conducted to determine if there was a difference between rankings given by younger and older drivers (Table 26). The result was not significant, indicating that there was not a difference between younger and older drivers for sign preference.

Table 26. Question 6 mean rankings for assessment by age.

Sign Color Combination	Younger	Older	Analysis by Age
Yellow on Purple (Non-Fluorescent)	3.7	3.7	$F_r(3,N=2)=6.0<$ $F_{tab}(alpha=0.05,df=3)=7.82$
Black on Fluorescent Yellow-Green	1.3	1.3	
Black on Fluorescent Coral	2.2	2.2	
Fluorescent Yellow on Fluorescent Purple	2.7	2.8	

*1 = most preferred, 4 = least preferred.

Trends in the Post-Test Questionnaire Data

Questions 1, 2, and 3 requested that the participants rate the sign they had seen while navigating the test route. Participants made the ratings without having seen the other experimental sign colors. For the assessment by sign color across the three ratings, the black on fluorescent yellow-green sign was rated as the most visible, as providing improved directional information, and as more useful than the other sign color combinations during both daytime and nighttime viewing conditions and by both younger and older drivers.

Driver preference for black on fluorescent yellow-green may result from the high luminance of the fluorescent yellow-green background during day and during night visibility conditions. In fact, fluorescent yellow-green had more than 4.5 times the luminance of the next brightest sign (non-fluorescent purple) during nighttime viewing. The retroreflectivity values for this sign paralleled its luminance; that is, the background of this sign yielded the highest coefficient of retroreflection (R_A) for any of the signs evaluated.

The luminance values may also explain the outcome of the ratings for the black on fluorescent coral sign and the non-fluorescent yellow on purple sign. The preference ratings across questions 1, 2, and 3 consistently show that the preference for black on fluorescent coral decreases at night and the preference for the non-fluorescent yellow on purple increases at night. Likewise, the black on fluorescent coral sign is rated higher than the non-fluorescent yellow on purple during the day and the reverse is true at night. This outcome is in alignment with the luminance values of the signs. Recall that during daytime visibility conditions, the black on fluorescent coral sign was the second most luminant sign; however, during nighttime visibility conditions, the black on fluorescent coral was the third most luminant sign following the non-fluorescent yellow on purple sign. Nonetheless, overall preference for the sign color combinations shows that the black on fluorescent coral is second to the black on fluorescent yellow-green. Conversely, the non-fluorescent sign is generally rated the least preferred, following the fluorescent yellow on fluorescent purple sign.

For questions 4, 5, and 6, participants looked at color samples of all four signs. This was the first time that the drivers had seen all four experimental colors. They were asked to rank the four colors in terms of visibility, readability, and overall preference from highest to lowest. These questions were not analyzed by visibility condition since survey respondents could not make comparisons for daytime versus nighttime conditions.

A review of the results reveals that the black on fluorescent yellow-green was consistently ranked the highest and the non-fluorescent yellow on purple was consistently ranked the lowest by both younger and older drivers.

Additional Comments

For the driving performance variables, there were very few occurrences of late braking maneuvers and wrong and missed turns. The driving performance results did not indicate significant differences between the four sign colors, leading one to surmise that the colors were equally conspicuous. The only data on which to recommend a unique sign color combination for incident management trailblazing are the subjective preference data.

Significant questionnaire results along with trend information suggest that the black on fluorescent yellow-green sign was the most preferred by both younger and older drivers. However, a Notice of Amendment to the MUTCD published in the *Federal Register* (Federal Highway Administration, 1998) stated that the fluorescent yellow-green color is to be used for warning signs related to pedestrian, bicycle, and school applications. This assignment has eliminated the opportunity to use fluorescent yellow-green as a unique sign color for trailblazing in incident management situations. Trend information also suggests that the non-fluorescent yellow on purple sign was the least preferred by both older and younger drivers.

With the elimination of these two signs, the remaining contenders for a unique sign color combination are black on fluorescent coral and fluorescent yellow on fluorescent purple. The only significant differences between these signs were for question 4, in which fluorescent coral was ranked significantly better for visibility, and for question 6, in which fluorescent coral was ranked significantly better for overall preference. For questions 1, 2, and 3, trend information suggests that the fluorescent yellow on fluorescent purple sign was more preferred than the fluorescent coral sign during nighttime viewing conditions and less preferred than fluorescent coral during daytime viewing conditions. For question 5, the fluorescent yellow on fluorescent purple sign was not significantly different from the fluorescent coral sign in terms of sign readability.

Based on these results, one could surmise that the shortcoming of the fluorescent coral sign is that it is less luminant at night. An important note regarding the fluorescent coral and fluorescent purple sign materials is that they were first generation overlay films that were thicker than is normal for full production run materials. It is reasonable to assume that full production run materials would be thinner, thereby increasing the nighttime luminance values and the detection distance of the signs. If the fluorescent coral sign were more luminant, it would also be reasonable to assume that the subjective preference for this sign color would improve during nighttime viewing conditions. Of course, one could argue that the preference for the fluorescent purple sign color would also improve during nighttime viewing conditions. To this the authors would submit that since the fluorescent coral is the preferred color during the daytime and ranked significantly higher than fluorescent yellow on fluorescent purple in terms of preference for visibility (question 4) and overall preference (question 6), the fluorescent coral sign is the best option for a unique sign color combination to be used for incident management trailblazing. Furthermore, the legend to background contrast ratio for the black on fluorescent coral sign was reduced at night due to a halation effect. If the arrow on the sign is made larger as suggested by the drivers in this study, the sign could have a considerably higher contrast ratio at night, thereby improving the its readability (question 5).

LIMITATIONS OF THE STUDY

There are several aspects of the research worth noting. First, many participants noted that larger directional arrows would be helpful. Larger arrows would have certainly increased the distance from which drivers could ascertain the directional information provided by these signs and might have reduced the number of late braking maneuvers and turn errors.

Second, as with all research in which an experimenter is present during task performance, there is the possibility that an observer effect may have biased some of the drivers' typical driving behavior. Based on experimenter observation, videotapes of the participants during the test drives, and comments made by participants during debriefing, it is likely that some of the drivers drove more cautiously than they normally would.

Third, although none of the participants indicated that he or she had driven the route, most of them had seen some of the signs. The route did not change over the approximate 2-month period during which the driving portion of the study was conducted. It should also be noted that news media coverage of this study was highlighted approximately halfway through the 2-month period in which participants were being recruited. It is possible that this situation may have affected the results documented here; however, there are no indications supportive of this possibility.

Fourth, this study did not evaluate driver responses in reduced visibility conditions associated with weather (e.g., fog, precipitation). Anecdotal evidence suggests that the use of fluorescent colors on signs greatly improves their conspicuity in low-level daylight conditions and reduced visibility during daylight conditions brought on by fog and precipitation. Future research should investigate driver response to fluorescent signs in reduced visibility conditions associated with weather.

Fifth, the fluorescent coral and fluorescent purple sign materials were laboratory-developed, non-production quality overlay films and were, therefore, thicker than typical production material. As such, the resulting nighttime luminance values were likely lower than would be expected after full-scale production.

FINDINGS AND CONCLUSIONS

- Driving performance was not significantly different between the four experimental sign color combinations.
- Trend information from the subjective preference questionnaire suggests that the black on fluorescent yellow-green sign was the most preferred by younger and older drivers during both day and night visibility conditions; however, this sign color has already been assigned by FHWA.
- Driver preference for the non-fluorescent yellow on purple sign consistently increased at night when the sign became more luminant; however, the overall preference for this sign color combination was lower than for the other sign color combinations tested in this study.
- Driver preference for the black on fluorescent coral sign consistently decreased at night when the sign became less luminant.
- Survey trend information suggests that fluorescent coral was more preferred than the fluorescent yellow on fluorescent purple sign during daytime viewing conditions and less preferred than the fluorescent yellow on fluorescent purple sign during nighttime viewing conditions.
- Fluorescent coral was ranked significantly more preferred than the fluorescent yellow on fluorescent purple sign in terms of visibility and for overall preference.
- Drivers in the experiment commented that the arrow was too small to determine directional information from a comfortable distance.

RECOMMENDATIONS

Based upon the research conclusions, driver comments, and federal regulations that have been enacted since the outset of this series of experiments, the following recommendations are made:

1. Since fluorescent yellow-green has already been assigned by FHWA, it is recommended that black on fluorescent coral be used as a unique sign color combination for incident management trailblazing. Black on fluorescent coral is the most preferred sign during daytime viewing conditions and was ranked significantly higher in terms of preference for visibility and overall preference. In addition, the overlay film used for the fluorescent coral sign was a first generation material that can reasonably be expected to result in improved nighttime luminance when produced in a full production run.

2. The directional arrow on the sign should be larger. Not only would a larger arrow increase detection of directional information, it would likely result in a reduced number of late braking maneuvers and turn errors along a trailblazed route.

IMPLEMENTATION ISSUES

Costs

The costs associated with implementing a rigid fluorescent coral sign, or a fluorescent purple sign, cannot be determined at this time. This is because their markets have not been developed nor their materials fully refined. One could assume that the final production materials would be in the same price range as other readily available fluorescent sign sheeting materials on the market today (i.e., fluorescent yellow-green). The final cost of these materials will also depend on the size of the market for their use and their market penetration over a period of time.

Sign Design

The final sign size and shape should be determined prior to implementation of an incident management trailblazing sign. Initial discussions with VDOT staff suggest that an initial sign be used to alert motorists to follow the directional information provided on subsequent signs of the same color. The remaining signs for the route would have only a directional arrow with no legend. If the signs were used in this manner, the arrows providing directional information could be as large as those used on the interstate system. However, if the signs along the trailblazing route were to have text and directional information combined, their size should be increased beyond the dimensions used in this study. It should be noted that this increase in size would increase costs.

Regardless of the final sign size and shape, the use of highly retroreflective fluorescent materials will necessitate larger directional arrows than those used in this study to provide motorists with needed information. The final sign design should incorporate a wider arrowhead and tail to provide more contrast for daytime and nighttime legibility. The higher performance materials tend to produce a halation effect that reduces the effective area of the arrow and the legibility of the directional information.

Manufacturing

The manufacturing of the signs should also be considered prior to implementation. The signs used for incident management trailblazing could be used as permanent flip-down placements, and others could be used in conditions where they need to be deployed rapidly. The flip-down placements would lend themselves more toward rigid signs, and the rapid deployment signs would be roll-up signs.

In either case, rigid versus roll-up, the signs with a black legend (fluorescent yellow-green and fluorescent coral) are better suited for manufacturing than the two purple signs. The signs with black legends allow for standard sign manufacturing practices to take place. The fluorescent purple and non-fluorescent rigid signs would require an additional step in manufacturing. That is, either purple overlay film or ink would need to be applied, and then the legend and border would need to be hand-cut and hand-applied. These additional steps would add time and cost to producing these signs.

In addition, current limitations in sign manufacturing prevent a two-step manufacturing process for roll-up signs. This in itself may be the limiting factor as to which background colors are suited for this use.

Degradation

Anecdotal evidence suggests that darker materials (i.e., purple) may degrade at a faster rate than lighter colors, such as fluorescent yellow-green and fluorescent coral. Signs that degrade at faster rates could pose problems with maintenance and replacement, thereby increasing costs.

The fluorescent coral sign is not immune to degradation issues. Care should be taken in the development and refinement of the color to prevent it from fading to resemble a weathered fluorescent orange sign. Work should be conducted by the American Society for Testing and Materials and FHWA to develop fluorescent color boxes to ensure that these colors are refined and meet the needs of the motoring public.

ACTION ITEM

VDOT should consider the recommendations presented and the implementation issues identified and determine whether a unique sign color would benefit the motoring public. If a unique sign color would be of benefit, then VDOT's Traffic Engineering Division should petition FHWA to use the fluorescent coral color to trailblaze motorists during incidents and request an amendment to the MUTCD to assign this color for incident management usage.

In the same petition, VDOT should ask FHWA to prohibit the evaluation of or experimentation with this color for any purposes other than incident management trailblazing. This might reduce the likelihood that the fluorescent coral color would have a dual assignment.

ACKNOWLEDGMENTS

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REFERENCES

Burns, D. M., & Johnson, N. L. (1997). Characterizing the visual performance of fluorescent retroreflective signing materials using the fluorescent luminance factor, Y_F. In *Proceedings of the Eighth Congress of the International Colour Association, 1*, 359-362. Kyoto, Japan.

Burns, D. M., & Pavelka, L. A. (1995). Visibility of durable fluorescent materials for signing applications. *Color Research and Application, 20*, 108-116.

Collins, B. L. (1987). Color appearance of traffic control devices under different illuminants. In *Transportation Research Record 1247*, pp. 23-31. Washington, DC: Transportation Research Board.

Dewar, R. E. (1988). Criteria for the design and evaluation of traffic sign symbols. In *Transportation Research Record 1160*, pp. 1-6. Washington, DC: Transportation Research Board.

Dewar, R. E. (1989). Traffic signs. *International Review of Ergonomics, 2*, 65-86.

Dewar, R. E. (1993). Traffic control devices, highway safety, and human factors. *Transportation Research Circular 414,* 12-20.

Federal Highway Administration. (June 19, 1998). 23 CFR Part 655. *Federal Register, 63*(118), 33546-33550.

Finn, P. & Bragg, B. W. E. (1986). Perception of risk of an accident by young and older drivers. *Accident Analysis and Prevention*, *18*, 289-298.

Hiatt, L. G. (1987). Designing for the vision and hearing impairments of the elderly. As cited in Pirkl, J. J. (1994). *Transgenerational Design: Products for an Aging Population.* New York: Van Nostand Reinhold.

Mace, D. (1988). Sign legibility and conspicuity. *Transportation in an Aging Society, Vol. 2,* pp. 270-293. (Transportation Research Board Special Report 218, 270-293). Washington, DC: Transportation Research Board.

Mortimer, R. G., & Fell, J. C. (1989). Older drivers: Their night fatal crash involvement and risk. *Accident Analysis and Prevention, 21*(3), 273-282.

Neale, V., Barker, J., Dingus, T., & Brich, S. (1999). Evaluation of unassigned sign colors for incident management trailblazing. In *Transportation Research Record 1692,* pp. 17-23. Washington, DC: Transportation Research Board.

Owsley, C. E., & Sloan, M. E. (1987). Contrast sensitivity, acuity, and the perception of "real-world" targets. *British Journal of Ophthalmology, 71,* 791-796.

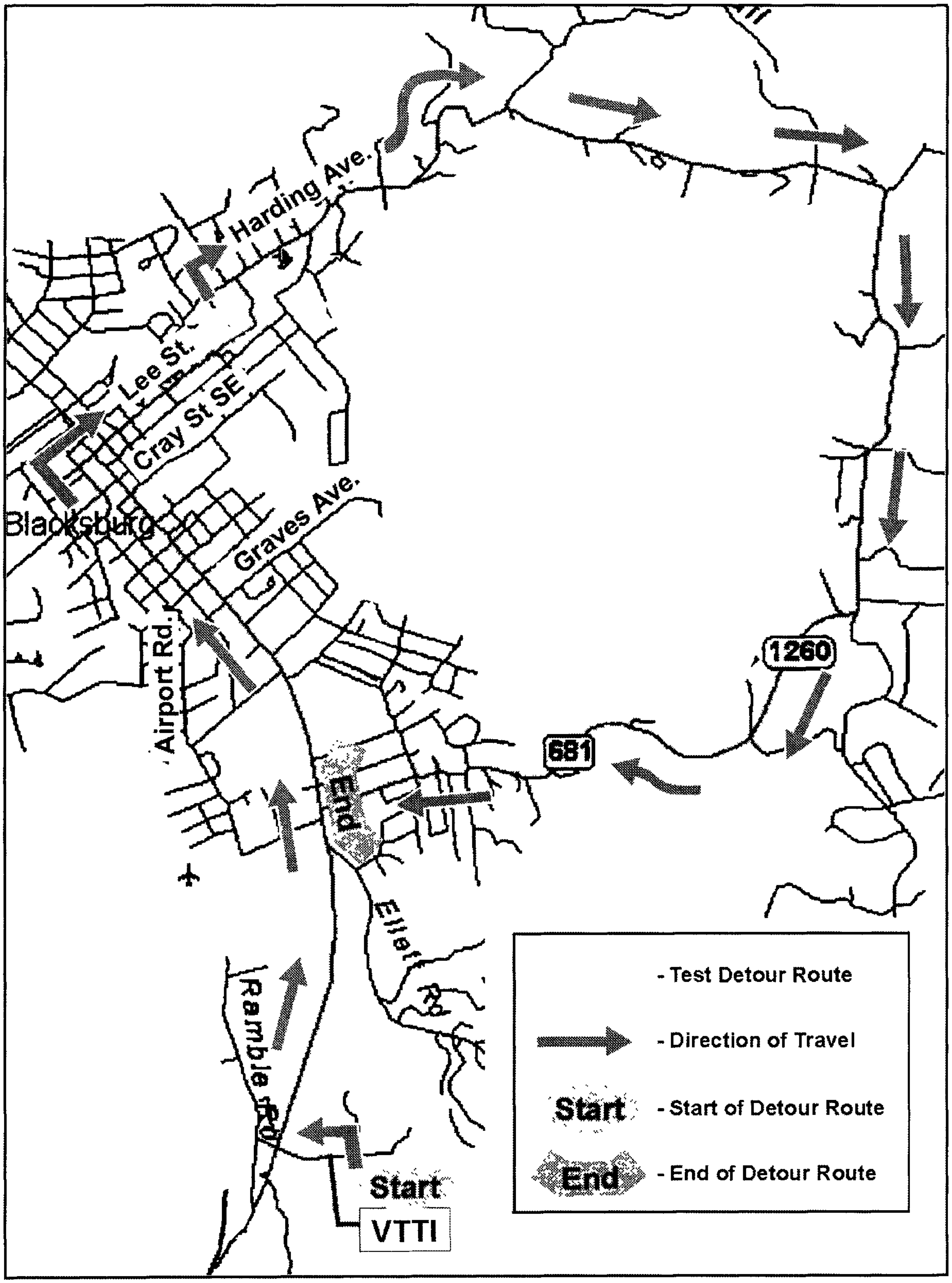
Pietrucha, M. T. (1993). Development of an emergency zone sign. In *Transportation Research Record 1421,* pp. 36-44. Washington, DC: Transportation Research Board.

Verriest, G. (1963). Further studies on acquired deficiency of color discrimination. *Journal of the Optical Society of America, 53,* 185-195. As cited in Boff, K. R., & Lincoln, J. E. (Ed.). (1986). *Engineering Data Compendium, Human Perception and Performance.* Wright-Patterson Air Force Base, OH: Harry G. Armstrong Aerospace Medical Research Laboratory.

U. S. Department of Transportation, Federal Highway Administration. (1983). *Traffic control devices handbook.* Washington, DC: Author.

Zwahlen, H. T., & Schnell, T. (1997). Visual detection and recognition of fluorescent color targets versus nonfluorescent color targets as a function of peripheral angle and target size. In *Transportation Research Record 1605*, pp. 28-40. Washington, DC: Transportation Research Board.

APPENDIX A. MAP OF TEST AREA WITH ROUTE HIGHLIGHTED



APPENDIX B. DESCRIPTION OF THE INSTRUMENTED VEHICLE

A 1995 Oldsmobile Aurora was used as the experimental vehicle for all participants. The instrumentation in the vehicle provided the means to unobtrusively collect, record, and reduce a number of data items, including measures of attention demand, measures of navigation performance, safety-related incidents, and subjective opinions of the participants.

Forward-View Camera

The forward-view camera provided a wide view of the forward roadway without substantial distortion. The camera had an auto-iris and provided a high-quality picture in all but the most severe daylight glare conditions. The forward-view camera was located in the center rear-view mirror and did not obscure any part of the driver's view of the roadway or impair his/her use of the mirror. The forward-view camera served to collect relevant data from the forward scene (e.g., traffic density, signs and markers, and headway).

Multiplexer and PC-VCR

A quad-multiplexer was used to integrate up to four camera views and place a time stamp onto a single videotape record. A PC-VCR received a time stamp from the data collection computer and displayed the time stamp continuously on the multiplexed view of the videotaped record. In addition, the PC-VCR had the capability to read and mark event data provided by the data collection computer and perform high-speed searches for event marks. The PC-VCR operated in an S-VHS format so that each multiplexed camera view would have 200 horizontal lines of resolution.

Data Collection Computer

The data collection computer provided reliable data collection, manipulation, and hard drive storage under conditions present in a vehicle environment. The computer had a 16-channel analog-to-digital capability, standard QWERTY keyboard, and a 9-inch diagonal color monitor. Computer memory and processing capabilities included: 12 megabytes RAM, a 1.2-gigabyte hard drive, and a Pentium processor.

Sensors

The steering wheel, speedometer, accelerator, and brake were instrumented with sensors that transmitted information about position of the respective control devices. The steering wheel sensor provided steering position data accurate to within ±1 degree. The brake and accelerator sensors provided brake position to within ±0.1 inch. An accelerometer provided acceleration readings in the lateral and longitudinal planes of the vehicle. The accelerometers provided values for vehicle acceleration and deceleration up to and including hard braking behavior, as well as intense turning. These sensors provided signals that were read by the A/D interface at a rate of 10 times per second.

Experimenter Control Panel and Event Flagger

A custom experimenter control panel was located in the vehicle and allowed the experimenter to record the occurrence of test sign events or other unplanned events in the data set by push-button input.

Video/Sensor/Experimenter Control Panel Interface

A custom interface was used to integrate the data from the experimenter control panel, driving performance sensors, event flagger, and speedometer with the data collection computer. In addition, the interface provided a means to accurately read and log the time stamp from the PC-VCR to an accuracy of ±0.1 second. The time stamp was coded such that a precise location could be synchronized from any of the videotaped records to the computer data record for post-test laboratory reduction and file integration.

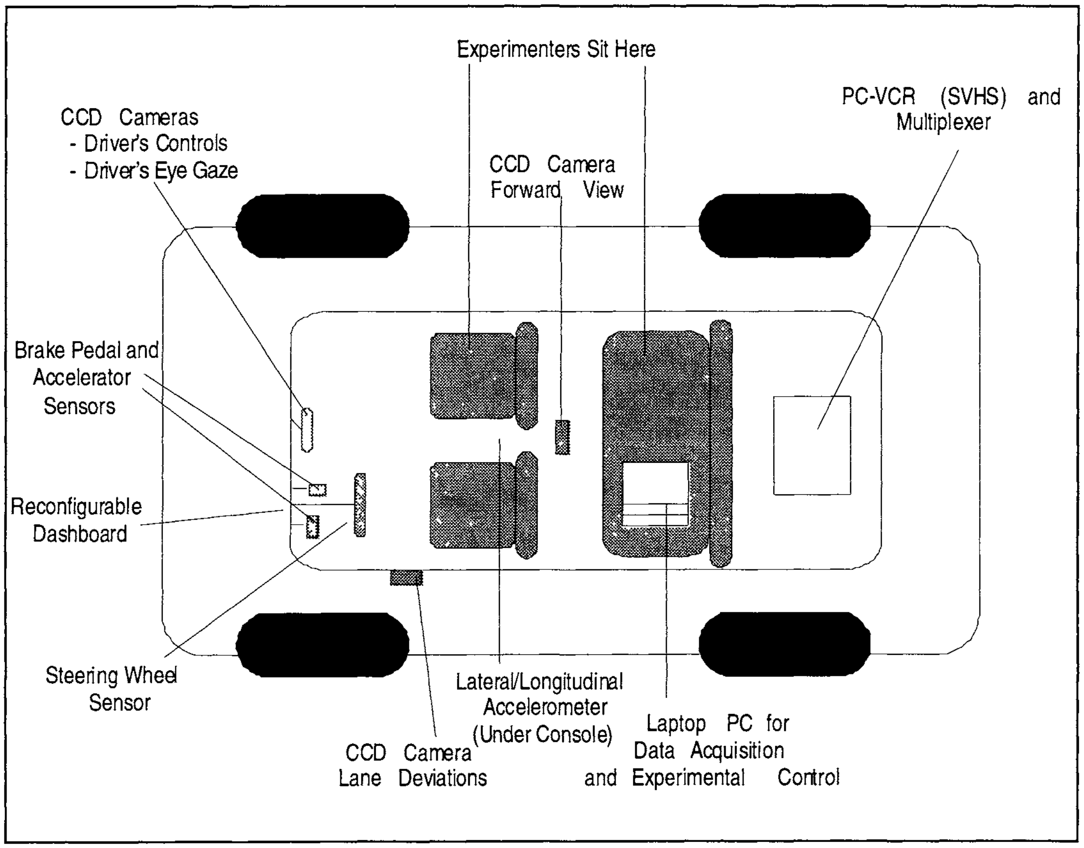


Figure B-1. Diagram of the instrumented vehicle.

Safety Apparatus

The test vehicle had the following safety apparatus provided as part of the instrumented vehicle system:

- All data collection equipment was mounted such that no hazard was posed to the driver.
- Participants were required to wear the lap and shoulder belt restraint system. The vehicle was equipped with a driver-side and passenger-side airbag supplemental restraint system.
- The vehicle had an experimenter's brake pedal mounted in the front passenger side.
- The vehicle had a fire extinguisher, first aid kit, and cellular phone for emergency use.
- None of the data collection equipment interfered with the driver's normal field-of-view.
- Emergency protocol was established prior to testing.

APPENDIX C. MANUFACTURING OF THE INCIDENT MANAGEMENT SIGNS

Fluorescent Yellow-Green

The fluorescent yellow-green signs required no special manufacturing requirements. They employed the traditional silk screening process. The non-reflective black legend and border were inked directly onto the fluorescent yellow-green Diamond Grade VIP™ sheeting.

Fluorescent Coral (Hot Pink)

The fluorescent coral (hot pink) signs required an extra step in the manufacturing process. These signs were constructed by overlaying the experimental film onto Diamond Grade VIP™ white retroreflective sheeting. The film required the technician to butt splice the material twice to cover the entire sign face. Once the overlay film was applied, the technician then inked the non-reflective black legend and border using the traditional screening process.

Fluorescent Purple

The fluorescent purple sign also used an experimental overlay film over the Diamond Grade VIP™ white retroreflective sheeting, but the legend and border were Diamond Grade VIP™ fluorescent yellow retroreflective sheeting. The process required only one butt splice in the overlay film. The legend and border required the technician to hand cut each letter and piece for the border and apply the respective pieces by hand.

Non-Fluorescent Purple

The non-fluorescent purple signs used purple ink over white Diamond Grade VIP™ retroreflective sheeting. The legend and border were Diamond Grade VIP™ yellow retroreflective sheeting. The white sheeting was flood coated with the purple ink. The legend and border required the technician to hand cut each letter and piece for the border and apply the respective pieces by hand.

APPENDIX D. APPARATUS AND PROCEDURES FOR LAB MEASUREMENTS FOR MANUFACTURED SIGNS

The primary apparatus used in obtaining the laboratory measurements contained in Table 2 included the following: (1) Minolta CS-100 chroma meter, (2) Minolta T-1 Illuminance meter, and (3) Macbeth® Spectralight® II lighting booth.

Minolta CS-100 Chroma Meter

A Minolta CS-100 tristimulus color chroma meter was used to obtain non-contact luminance measurements (chromaticity vales in Y, x, y) of the signs used in Phase III.

Iluminance Meter

A Minolta T-1 illuminance meter was used to obtain illuminance measurements of the conditions in the lighting booth. The measuring range for this device is 0.019 to 900 lx (0.019 to 990 ft-c).

Macbeth® Spectralight® II lighting booth

The Macbeth® Spectralight® II lighting booth was used to simulate a typical daytime viewing condition for signs used in Phase III. The lighting booth was used to produce an average day lighting condition of 572 lux (measured vertically, i.e., parallel with the color sign).

Procedure

For this study, measurements were taken only during simulated daylight since we were interested in color contrast. Color contrast is related to the perception of color differences and is very important during daylight conditions. Measurements were taken approximately 1 meter from the sign samples. The vertical illumination from the Macbeth® Spectralight® II lighting booth was approximately 572 lux, located 64 cm above the sample signs. Contrast calculations were derived using the following formula:

$$\text{Contrast ratio} = L_{max}/L_{min},$$

where L_{max} is the maximum luminance and L_{min} is the minimum luminance in cd/m^2.

APPENDIX E. POST-TEST QUESTIONNAIRE

VIRGINIA TECH TRANSPORTATION INSTITUTE
SIGN CONSPICUITY STUDY

User Survey

Participant ID: ______________	Date: __________

Please read the following questions and circle the number that best describes how you feel.

1. How visible was the "test route" sign relative to the environment?

1	2	3	4	5
Not visible	Somewhat Visible	Moderately visible	Very visible	Extremely visible

2. How easy was it to identify, or understand, the directional information provided by the test signs?

1	2	3	4	5
Not easy	Somewhat easy	Moderately easy	Very easy	Extremely easy

3. How useful would you find this type of sign design for providing temporary directional/detour information while driving?

1	2	3	4	5
Not useful	Somewhat useful	Moderately useful	Very useful	Extremely useful

User Survey (continued, Page 2)

Participant ID: __________	Date: ___________

Please answer the following questions using the sign samples provided by the experimenter.

Please use the color definitions provided with the sign samples.

Black on Fluorescent Yellow-Green
Non-Fluorescent Yellow on Non-Fluorescent Purple
Black on Fluorescent Coral
Fluorescent Yellow on Fluorescent Purple

4. Please rank the signs in order of preference for visibility along the roadway, or how well you feel the signs would stand out from the environment and other signs along the roadway. Use the following definitions of visibility to rank the sign samples:

Most visible ____________________
More visible ____________________
Somewhat visible ____________________
Least visible ____________________

5. Please rank the signs in order of preference based on how easy you feel the signs are to read. Use the following definitions of readability to rank the sign samples.

Most readable ____________________
More readable ____________________
Somewhat readable ____________________
Least readable ____________________

6. Please rank the signs in order of overall preference for use on signs providing temporary directional/detour information. Use the following definitions of preference to rank the sign samples.

Most preferred ____________________
More preferred ____________________
Somewhat preferred ____________________
Least preferred ____________________

APPENDIX F. INFORMED CONSENT FORM

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY
Informed Consent for Participants of Investigative Projects

Title of the Project: *On-road Investigation of Fluorescent Colors to Determine Improvements of Conspicuity for Traffic Signs*
Investigators: Richard L. Anders and Dr. Vicki L. Neale

I. THE PURPOSE OF THIS RESEARCH

The purpose of this research project is to evaluate specific traffic sign designs relative to a current sign design standard in an on-road field study. This research continues the evaluation of previously determined color and letter size combinations, and will investigate the visibility and conspicuousness, relative to the current sign design standard, of the sign designs that resulted in the greatest legibility distances during the previous parts of this research program. Participants will drive an instrumented vehicle along a predetermined route in a normal traffic situation, and will follow the directional information provided by the test signs. For safety considerations, data collection will occur when on dry pavement and an experimenter will be present in the car during the data collection session. The results of this study will help traffic engineers to design more visible, conspicuous, and legible traffic signs based on the color and design parameter information obtained. The study involves 96 observers of varying age and gender.

II. PROCEDURES

During the course of this experiment you will be asked to perform the following tasks:

1. Complete a short demographic survey (over the phone).
2. Read and sign an Informed Consent Form.
3. Complete a simple vision test and color vision test.
4. Complete a brief health-screening questionnaire.
5. Listen to the instructions regarding the task that you will be performing.
6. Read general information about the operation of the experimental vehicle.
7. Participate in a training session in which you will learn about specific features of the experimental vehicle.
8. Perform one experimental drive with the vehicle over a pre-determined route in which data will be collected.
9. Answer questions regarding your subjective assessment of the signs displayed during your drive.

At the end of the experimental run, you will drive back to the original location, be paid for your time, and debriefed about the research. The total experiment time will be approximately one hour.

It is important for you to understand that we are evaluating the traffic signs, not you. Therefore, we ask that you perform to the best of your abilities. If you ever feel frustrated in attempting to read a test sign, just remember that this is the type of thing that we need you to comment on. The information and feedback that you provide is very important to this project.

III. RISKS

There are some risks or discomforts to which you are exposed in volunteering for this research. These risks are:

(1) The risk of an accident normally associated with driving an automobile in light or moderate traffic, as well as on straight and curved roadways.
(2) Possible fatigue due to the length of the experiment. If you deem it necessary, rest breaks will be provided.
(3) You will be videotaped by cameras while driving the vehicle. Due to this fact, you will be asked not to wear sunglasses. If this at any time during the course of the experiment impairs your ability to drive the vehicle safely, please so notify the experimenter.

The following precautions will be taken to ensure minimal risk to you:

(1) An experimenter will monitor your driving and will ask you to stop if they feel the risks are too great to continue. However, as long as you are driving the research vehicle, it remains your responsibility to drive in a safe, legal manner.
(2) You will be required to wear the lap and shoulder belt restraint system while in the car. The vehicle is also equipped with a driver's side and passenger's side airbag supplemental restraint system.
(3) The vehicle is equipped with an experimenter brake pedal if a situation should warrant braking and you fail to brake.
(4) The vehicle is equipped with a fire extinguisher, first-aid kit, and a cellular phone.
(5) If an accident does occur, the experimenters will arrange medical transportation to a nearby hospital emergency room. You will be required to undergo examination by medical personnel in the emergency room.
(6) All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case.
(7) None of the data collection equipment interferes with any part of your normal field of view present in the automobile.

IV. BENEFITS OF THIS RESEARCH

There are no direct benefits to you from this research other than payment for participation. No promise or guarantee of benefits is made to encourage you to participate. Your participation will provide baseline data for visibility and conspicuousness of highway traffic signs composed of various design parameters and colors. This may have a significant impact on highway traffic sign effectiveness when these color combinations and design parameters are employed, as well as on driving safety. Ultimately, the results of these data may significantly affect highway traffic signing as specified by the Virginia Department of Transportation and the Federal Highway Administration.

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The data gathered in this experiment will be treated with confidentiality. Shortly after participation, your name will be separated from your data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 1). You will be allowed to see your data and withdraw the data from the study if you so desire, but you must inform the experimenters immediately of this decision so that the data may be promptly removed. At no time will the researchers release the results of this study to anyone other than individuals working on the project without your written consent.

VI. COMPENSATION

You will receive $15.00 total for your participation in this study. This payment will be made to you at the end of your voluntary participation in this study for the portion of the study that you complete.

VII. FREEDOM TO WITHDRAW

As a participant in this research, you are free to withdraw at any time for any reason. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any questions or respond to any research situations without penalty.

VIII. APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Transportation Institute.

IX. PARTICIPANT'S RESPONSIBILITIES

If you voluntarily agree to participate in the study, you will have the following responsibilities: To be physically free from any illegal substances (alcohol, drugs, etc.) for 24 hours prior to the experiment, and to conform to the laws and regulations of driving or public roadways.

X. PARTICIPANT'S PERMISSION

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. If I participate, I may withdraw at any time without penalty. I agree to abide by the rule of this project.

____

Participant's Signature Date

Should I have any questions about this research or its conduct, I may contact:

Richard L. Anders, Investigator (540) 231-1564
Vicki L. Neale, Principal Investigator (540) 231-1514
Thomas A. Dingus, Director, VA Tech Trans. Institute (540) 231-1502
H. T. Hurd, Chair

APPENDIX G. HEALTH SCREENING QUESTINNAIRE

Health Screening Questionnaire

Participant ID: __________

NOTE TO INTERVIEWER: This is a two-part questionnaire. The first part may be completed during initial screening process. The second part must be completed and signed immediately prior to participation in the study.

1. Are you in good general health? Yes No

   If no, please list any health-related conditions you are experiencing or have experienced in recent past.

   ____

   ____

2. Have you, in the last 24 hours, experienced any of the following conditions?

Inadequate sleep	Yes	No
Unusual hunger	Yes	No
Hangover	Yes	No
Headache	Yes	No
Cold symptoms	Yes	No
Depression	Yes	No
Allergies	Yes	No
Emotional upset	Yes	No

3. Do you have a history of any of the following?

   Visual Impairment Yes No
   (If yes, please describe.)

   ____

   ____

   Hearing Impairment Yes No
   (If yes, please describe.)

   ____

   ____

   Seizures or other lapses of consciousness Yes No
   (If yes, please describe.)

   ____

   ____

   Any disorders similar to the above or that would impair your driving ability?
   Yes No

(If yes, please describe.)

____

____

4. If you are female, are you pregnant? Yes No

5. List any prescription or non-prescription drugs you are currently taking.

____

____

6. List any prescription or non-prescription drugs you have taken in the last 24 hours.

____

____

____

7. List the approximate amount of alcohol (beer, wine, fortified wine, or liquor) you have consumed in the last 24 hours.

____

____

8. List the approximate amount of caffeine (coffee, tea, soft drinks, etc.) you have consumed in the last 6 hours.

____

____

9. Are you taking any drugs of any kind other than those listed in questions 5 or 6?

Yes No

____________________________ ____________________________

Signature Date

APPENDIX H: STATISTICAL TABLES FOR SURVEY QUESTIONS

Significant p or z values are indicated by an asterisk in the right hand column.

Table H-1. Analysis of variance table for question 1.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sign Color	**3**	**7.8450**	**2.6150**	**6.73**	**0.0004**
Age	1	0.3057	0.3057	0.79	0.3779
Visibility Condition	1	0.8982	0.8982	2.31	0.1325
Sign Color X Age	3	0.0593	0.0198	0.05	0.9847
Sign Color X Visibility Condition	3	2.4483	0.8161	2.10	0.1072
Visibility Condition X Age	1	0.0140	0.0140	0.04	0.8498
Sign Color X Age X Visibility Condition	3	2.432	0.8107	2.09	0.1090
Error	75	29.1333	0.3884		
TOTAL	90	43.1358			

Table H-2. Analysis of variance table for question 2.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sign Color	**3**	**7.8875**	**2.6292**	**2.36**	**0.0783**
Age	**1**	**8.1969**	**8.1969**	**7.35**	**0.0083**
Visibility Condition	1	1.1793	1.1793	1.06	0.3070
Sign Color X Age	3	1.2774	0.4258	0.38	0.7663
Sign Color X Visibility Condition	**3**	**11.7106**	**3.9035**	**3.50**	**0.0195**
Visibility Condition X Age	1	0.5337	0.5337	0.48	0.4911
Sign Color X Age X Visibility Condition	3	2.0319	0.6773	0.61	0.6121
Error	75	83.6000	1.1147		
TOTAL	90	116.4173			

Table H-3. Analysis of variance table for question 3.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sign Color	**3**	**7.8908**	**2.6303**	**2.42**	**0.0727**
Age	1	1.9653	1.9653	1.81	0.1828
Visibility Condition	1	1.3571	1.3571	1.25	0.2674
Sign Color X Age	3	1.0886	0.3629	0.33	0.8009
Sign Color X Visibility Condition	3	6.1322	2.0441	1.88	0.1402
Visibility Condition X Age	1	0.0659	0.0659	0.06	0.8062
Sign Color X Age X Visibility Condition	3	2.6669	0.8890	0.82	0.4881
Error	75	81.5333	1.0871		
TOTAL	90	102.7001			

Table H-4. Pairwise comparisons for question 4, assessment by sign color.

Sign Color Background	Difference between Rank Sums $z(\alpha=0.05, \#c=6)=2.638$, $z_{critical} = 45.95$
Yellow-Green vs Non-Fl Y/P	236*
Yellow-Green vs Coral	83*
Yellow-Green vs Fl Y/P	159*
Non-Fl Y/P vs Coral	153*
Non-Fl Y/P vs Fl Y/P	77*
Coral vs Fl Y/P	76*

*Significant difference, $z_{calculated} > z_{critical}$

Table H-5. Pairwise comparisons for question 5, assessment by sign color.

Sign Color Background	Difference between Rank Sums $z(\alpha=0.05, \#c=6)=2.638$, $z_{critical} = 45.95$
Yellow-Green vs Non-Fl Y/P	222*
Yellow-Green vs Coral	102*
Yellow-Green vs Fl Y/P	142*
Non-Fl Y/P vs Coral	120*
Non-Fl Y/P vs Fl Y/P	80*
Coral vs Fl Y/P	40

*Significant difference, $z_{calculated} > z_{critical}$

Table H-6. Pairwise comparisons for question 6, assessment by sign color.

Sign Color Background	Difference between Rank Sums $z(\alpha=0.05, \#c=6)=2.638$, $z_{critical} = 45.95$
Yellow-Green vs Non-Fl Y/P	219*
Yellow-Green vs Coral	84*
Yellow-Green vs Fl Y/P	131*
Non-Fl Y/P vs Coral	135*
Non-Fl Y/P vs Fl Y/P	88*
Coral vs Fl Y/P	47*

*Significant difference, $z_{calculated} > z_{critical}$