Improvement of Conspicuity for Trailblazing Signs

by

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(ABSTRACT)

This report documents research conducted to design and evaluate a new traffic sign design for marking, or trailblazing, emergency detour routes. The purposes of this research are twofold: 1) to evaluate and obtain field data on the use of test signs featuring four currently unassigned background traffic sign colors, sign legend colors, and other design parameters in order to determine which combination will produce the best legibility distances; and more importantly 2) to develop a recommendation for the most conspicuous and effective sign design to be used for trailblazing alternate routes and incident management purposes.

The research was conducted in two parts, an off-road field study of sign legibility (Study 1) and an on-road field study of sign conspicuity (Study 2). Study 1 was conducted to determine the sign color combination, letter stroke width, and letter size that produced optimal legibility results. The results of Study 1 revealed that several color combinations produced better legibility results than traditional orange and black signs. Based upon those results, three color combinations were chosen for testing (coral with black legend, light blue with black legend, and purple with yellow legend) against a baseline color combination of orange with black legend. The test signs to be further tested featured 125-mm (5 in), series D letters.

Study 2 was conducted using an instrumented vehicle through a construction zone-related detour and a survey questionnaire. The independent variables included sign color combination, age, and visibility condition. The findings of Study 2 indicated that use of a color combination other than the traditional orange background with a black legend will improve driver performance and safety when used for trailblazing during incident management situations.

Based on the combined results and other anecdotal evidence from Studies 1 and 2, the following conclusions and recommendations were made:

- A color combination other than traditional orange and black should be used for trailblazing during incident management situations, especially when trailblazing alternate routes around existing detour/construction zones.
- Coral signs with black legends should not be used for trailblazing around a critical incident.

- A light blue on black sign is recommended for use for trailblazing during critical incidents due to its generally favorable subjective ratings and for minimization of the number of turn errors made by drivers in an overlapping detour.
- Despite the preceding recommendation, it is important to note that the light blue sign with black legend fades to take on the appearance of a regulatory sign when headlights or other strong lighting reflect onto it.
- If the light blue and black sign is deemed inappropriate due to its similarity to a regulatory sign at night, consider using the purple and yellow color combination. In this study, the yellow on purple sign color combination resulted in fewer turn errors than black on orange and it was generally rated favorably by drivers.

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CHAPTER 1. INTRODUCTION

Roadway congestion has grown significantly in recent years, leading to a corresponding increase in the number of traffic incidents occurring on these roadways. Traffic incidents can block roadways for hours, forcing traffic to be diverted from the primary route onto a secondary street system, and then back to the primary route. Such diversion routes need to be marked, or "trailblazed," so that motorists unfamiliar with the area can safely navigate the alternate route. Because the primary roadways are often laden with construction zones, the typical orange and black "Emergency Detour" signs, which are often used to mark temporary secondary routes that partially overlap primary detour routes marked by orange and black "Detour" signs, may be ineffective for trailblazing temporary secondary routes. The problem arises when these emergency, or incident management, signs must compete with other standard orange and black construction zone signs as well as standard orange and black detour signs. In addition, these detour signs also must compete for the motorist's attention with other standard highway signs and commercial advertisement signs (Agaki, Seo, and Motada, 1996; Smith and Faulconer, 1971; Massie, Campbell, and Williams, 1995).

Ogden, Womack, and Mounce (1990) noted that there are several problems associated with construction traffic control, specifically on arterial roadways in urban areas, that are not currently addressed in the *Manual on Uniform Traffic Control Devices* (U. S. Department of Transportation, 1993). The problems encountered by drivers include: increased driver workload associated with construction sign requirements, constricted rights-of-way, moderate speed and volume combinations, compressed spacing between signalized intersections, heavy protected and unprotected turning movements, and excessive provisions for access to adjacent property (driveways).

To illustrate the deficiencies existing in the current traffic signing system, Ogden et al. (1990) conducted a survey that addressed the question of whether drivers have difficulty getting to their destinations because of construction or signing in the construction area. One-half of the people who participated in this survey answered "yes" when asked, "Do you have trouble finding certain places you want to go because of the construction?" This difficulty may be due to inconsistent signing through the construction zones and alternate routes, or the information provided by the signs may not be presented in a way that motorists can understand and follow. In either case motorist understanding of traffic signing when encountering these types of problems is critical to ensure that communication promotes good operations and safety, and yet research has shown that the communication of critical or important information to drivers is not sufficient using current construction zone practices.

Problems such as these have led to increased concern regarding the overall effectiveness of signs used to direct drivers through construction zones. Of particular interest in the current study is use of the black on orange Emergency Detour sign used for critical incident management, predominantly around work zones. The emergency detour signs currently in use employ the black on orange color scheme that is associated with construction activities. In a study on developing emergency road signs, Pietrucha (1993) concluded that there should be a separate category of traffic signs, i.e., independent of construction signs, to control traffic in an emergency situation. He referred to this category as an emergency zone sign, and recommended using brilliant yellow-green for this class of signs.

When faced with driving conditions such as those described above, motorists need traffic signs that can be seen, recognized, and understood quickly. This requires that the signs be sufficiently legible, conspicuous, and understandable. Legibility has been shown to be an effective measure for assessing the effectiveness of traffic signs since a traffic sign must be read if the message is to be communicated (Gordon, 1984). Similarly, Dewar (1993) suggested that the ultimate index of the adequacy of a traffic sign is how quickly and clearly the message is understood by drivers. Researchers (e.g., Dewar, 1993) agree that signs should be quickly understood since drivers have only one or two seconds to interpret and respond to the sign's message. Motorists must have sufficient time to make decisions and to take safe and appropriate action relative to a constantly changing combination of driving conditions. Sufficient decision-making and reaction time reduces the necessity for sudden, hazardous maneuvers (U. S. Department of Transportation, 1983). As such, it is important to warn drivers well in advance of hazardous situations or circumstances.

To effectively manage traffic when an incident occurs, there is a need to identify the most conspicuous sign color, the best contrast colors for the legend and border, and other factors that will effectively guide motorists unfamiliar with the detour route, even when that route traverses through work zones.

RESEARCH GOALS

The primary goal of this research was to evaluate the visual performance of retroreflective signs of various color combinations and letter design parameters for the purpose of identifying the legend and background color combination and other design parameters that are most effective for critical incident management situations. The modified sign design would provide a means for conveying conspicuous emergency detour or other critical incident management information to motorists regardless of other traffic sign information. Modifications believed to increase legibility and conspicuity of traffic control signs and considered for this research include color, contrast (color contrast, luminance contrast, and contrast ratio), and letter stroke width. Research was limited to purple, light blue, coral, and brilliant yellow-green background colors, all four of which are currently unassigned by the MUTCD (*Manual for Uniform Traffic Control Devices*, U. S. Department of Transportation, 1988), on Scotchlite™ Diamond Grade reflective sheeting materials, as well as a combined white and blue background, also on Scotchlite™ Diamond Grade reflective sheeting material. Legend colors for each background color were selected after an analysis of luminance contrast and color contrast using standard highway sign colors. Four letter stroke width values, which are dependent upon both the letter series and letter height used, were examined, including the standard values used on the current black on orange Emergency Detour traffic control sign. (Note that this research does not include investigation of fluorescent colors. While brilliant yellow-green was being considered, the color specified for this research was not the fluorescent strong yellow-green that has been proposed for use for non-motorized crossings and incident management.)

Another goal of this research was to obtain field data on the use of full-sized (0.610 m by 0.762 m, or 24 in by 36 in) test signs featuring purple, light blue, coral, and brilliant yellow-green backgrounds, all of which have been identified as having a potential application in traffic signing. Most, if not all, of the research cited deals with the standard sign colors, primarily red, green, blue, yellow, black, orange, and white. Little research has been conducted to examine use of the four colors currently unassigned by the MUTCD.

The driver response the stated design parameters was examined in terms of the following:

1. The legibility of the experimental sign color combinations and letter design parameters relative to the standard highway black on orange traffic control sign with respect to driver age and visual abilities in an off-road field study.

2. The legibility of the experimental sign color combinations and letter design parameters relative to the standard highway black on orange traffic control sign with respect to light conditions in daytime and at night in an off-road study.

3. The conspicuity of a specified subset of the experimental sign color combinations relative to the standard highway black on orange traffic control sign in an on-road field study, under normal traffic conditions, with respect to driver age and day and night driving conditions.

4. The legibility and understandability of a specified subset of the experimental sign color combinations relative to the standard highway black on orange traffic control sign in an on-road field study, under normal traffic conditions, with respect to driver age and day and night driving conditions.

It is expected that the results of this research will yield a new sign design configuration capable of providing both greater sign legibility and conspicuity under both day and night conditions for the range of driver abilities. Ultimately, the modified sign design shall provide a means for conveying important emergency detour trailblazing or other critical incident management information to motorists while at the same time ensuring that the information is not redundant with other construction-related information. The expected benefits of a modified incident management traffic control sign design include improved safety as a result of increases in the level of driver awareness of traffic direction information or more timely awareness of such information, especially during incident management situations. In addition, it is expected that driver comfort will be increased due to better guidance through earlier detection and color recognition and better sign legibility. Finally, it is expected that older drivers will benefit due to the age-related need for enhanced color contrast and brightness in traffic control signs. As a result, it is envisioned that this research will yield a recommendation for a sign color combination and related sign design parameters for incident management that will ultimately become a state and national standard.

CHAPTER 2. LITERATURE REVIEW

The literature of interest regarding this research area includes various aspects of the driving population and traffic control signs. Topics of interest include drivers' limitations and abilities, age-related differences and related physiological changes, and the use of and design considerations related to traffic signs. Factors that relate to the current research area have been grouped into two general topic areas: characteristics of the driving population and traffic signs.

CHARACTERISTICS OF THE DRIVING POPULATION

Driver Needs

The literature indicates that many human characteristics and individual differences influence the ability of drivers to obtain information from traffic signs and to take safe and appropriate action in response to those signs. These characteristics and differences affect drivers' needs, or the drivers' limitations and abilities that should be taken into account when designing the traffic control system. According to Dewar (1989), the worst-case scenario of drivers' needs requires that signing information should be easily obtained and used by drivers with the minimum visual acuity (20/40), slow reaction time, and susceptibility to confusion from information overload.

Before a motorist can guide his or her vehicle along the proper path, he or she must be able to see the traffic sign, read the message, and understand its meaning. Factors that can interfere with or distract the motorist from these tasks include the following: sign location relative to the roadway; legend style and size; contrast between the sign legend and background, which is especially important for seeing the sign at night or under darkened conditions; contrast between the sign and its environmental background, which affects the motorist's ability to see and distinguish a sign from other elements in the environment; and a sign border to distinguish the sign's geometrical shape, which does not occur naturally and provides contrast between the sign and its environmental background (U. S. Department of Transportation, 1983).

After the motorist sees the sign, he or she must decide what action to take based on his or her interpretation of the sign's meaning. According to the *Traffic Control Devices Handbook* (U. S. Department of Transportation, 1983), there are several factors that should be considered in order to assist the motorist in this task. These factors include motorist comprehension, emphasis, expectancy, uniformity, and sign consistency. First, the sign's message should be logical, which minimizes misinterpretation and ambiguity. Second, the more important information should be emphasized by size, location, or letter type. Third, the sign's legend and its location must conform to the motorist's expectation. Fourth, signs must maintain uniformity; thus, similar types of information must be presented similarly for similar decision situations. Finally, sign designs should be consistent; similar types of information should be kept in the same general location on sign panels.

Use of signs is prevalent and most messages are so well known by drivers that they are often taken for granted. As a result, drivers pay little attention to signs, and frequently miss important information or see it too late. MacDonald and Hoffman (1991) suggested that drivers' limited attentional capacity causes drivers to be less likely to report traffic signs in visually complex and attention-demanding environments, such as in the vicinity of major intersections, or more generally, in urban areas compared with rural areas. Studies by Summala and Näätänen (1974), in which drivers were deliberately searching for traffic signs, provide supporting evidence for this point of view. According to MacDonald and Hoffman (1991), even a sign of optimum design in terms of legibility of information display, accuracy and speed of driver comprehension, and sign conspicuity may be ineffective due to low levels of drivers' "registration" of road signs.

Other researchers have argued that a low level of awareness of sign information is normally due to drivers' "deficient motivation" rather than to physical characteristics of the sign, the environment, or drivers' visual systems. While drivers seem to have the perceptual skills needed for adequate use of traffic signs, sign information is often ignored, or goes unnoticed, because it is often redundant or of low subjective importance in relation to competing sources of information as seen by the drivers' own eyes or as indicated by experience. While there is a significant component of traffic sign information that is available primarily or exclusively on signs (e.g., changes in speed limit or directions to a destination), drivers' immediate responses appear to be related to the subjective rating of sign importance, and responses are often the result of fear of penalty for noncompliance. (MacDonald and Hoffman, 1991; Näätänen and Summala, 1976; Summala and Hietamäki, 1984; Dewar, Kline, and Swanson, 1994)

Gordon (1981) conducted a study investigating the informational load of highway guide signs. His results suggested that sign interpretation can be improved if the driver is aided or relieved of decision making. He also suggested that drivers could spend less time reading signs if sign reading could be reduced to simple visual scanning for a predetermined destination.

Age-related Differences in Driving

For the first time in U. S. history, there are more Americans over the age of 65 than under the age of 25 (Abrams and Berkow, 1990). In fact, the elderly population is growing in both number and in the proportion of the general population, and these trends are expected to continue (National Research Council, 1988). In addition, the U. S. Department of Transportation (1986) has reported that miles driven annually by older drivers have increased. Accident rates (accidents per 100,000 miles driven) are highest for older (typically over 65) and younger (typically under 25) adult drivers, while involvement rates for middle adult drivers (30 to 64 years of age) are below the average rate for involvement at all levels of severity (Lauer, 1952; Massie et al., 1995). The high rate of accidents associated with younger drivers is presumably due to driver inexperience, while physiological factors affect older drivers.

Researchers agree that it is essential to consider the needs and limitations of older drivers when designing traffic control devices due to the fact that older drivers experience a disproportionate level of difficulty when driving, especially at night. While most older people maintain good eyesight well into their seventies and eighties (National Institute on Aging, 1986), most people will experience one or more moderate changes in visual ability, including the following:

- reduced visual acuity beyond age 50, especially under low levels of illumination (Richards, 1977; Sturgis and Osgood, 1982; Sturr, Kline, and Taub, 1990);
- poor contrast sensitivity;
- lower amount of light entering the eye due to combination of yellowing of the lens and decreasing pupil size, both of which occur with age and result in a reduction in light transmissivity to the retina;
- higher degree of glare sensitivity and slower recovery from glare due to headlights, advertising signs, and street lights;
- poorer perception of color (which may reduce the effectiveness of color coding on signs);
- need for higher levels of illumination;
- difficulty adapting from darkness to brightness;
- narrowed field of vision; and
- reduction in eye speed movement and deterioration of visual scanning behavior.

In addition, elderly drivers often 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 can increase decision times (Hiatt, 1987; Dewar, 1989, 1993; Mortimer and Fell, 1989). Mortimer and Fell suggested that the physiological changes experienced by older drivers require that the traffic control system provide older drivers with more information and more time to respond than younger drivers. In addition, Owsley and Sloane (1987) reported that higher levels of contrast are needed by older persons to identify and discriminate real-world targets, including traffic signs. As a result of these factors, as well as the increasing numbers of older drivers and the high accident rates for both older and younger drivers, the need for research involving the problems of elderly road users, in addition to the young and middle driving population, has grown dramatically.

Color Recognition and Color Vision

According to Post (1992), many researchers have attempted to determine the exact number of colors that can be recognized reliably, and he summarized much of the relevant research. Estimates of the maximum number of colors that can be recognized reliably vary from as few as 5-8 colors to as many as 60 colors. Post noted that the variability in the reported findings was attributable to differences in the experimental methodologies used and to differences in hue or hue, saturation, and/or brightness.

Color recognition studies conducted by Boynton and Olson (1987) and Uchikawa and Boynton (1987) determined that 11 basic color terms could be used to describe recognized colors. These terms include white, black, red, green, yellow, blue, brown, gray, orange, purple, and pink. Boynton and Olson found a consistent use of these eleven terms for about 70 percent of the color judgments in their study. Uchikawa and Boynton suggest that the physiological basis for color sensation is independent of genetic or cultural differences between Americans and Japanese. The data strongly suggest that these color codes tap basic color sensations that observers agree on and recognize readily.

The determination of appropriate and recognizable colors for safety color coding is complicated by the fact that approximately 8 to 10 percent of the U. S. male population is color-blind or color-deficient from birth. In addition, approximately 1 percent of females have some form of color deficiency. A red-green deficiency (deuteranopia, protanopia) is most common; yellow-blue (tritanopia) is rare. Adults aged 20 to 24 have the best color discrimination, with an irregular decline occurring with age. The blue-yellow sensitivity often increases with age; this is due to a narrowing of the pupil and changes (i.e., yellowing) of the lens (Collins, 1989; Verriest, 1963).

Day versus Night Driving

Massie et al. (1995) noted that nighttime driving is generally associated with a higher risk of crash involvement due to factors such as reduced visibility, fatigue, and higher incidence of alcohol use. Statistics for driving reveal that there are more than nine crash involvements for every 100 million miles driven at night, as opposed to approximately six crash involvements during the day (Massie et al., 1995). The data also show that injury involvements are almost two times as great per 100 million miles at night, and fatal involvements are more than four times as likely per 100 million miles (Massie et al., 1995). A contributing factor in some of these incidents is the significant decrease in the visibility of road signs at night, with the problem being more pronounced for older drivers and drivers with color vision deficiencies. Glare is also a problem for drivers of all ages. Improvements in traffic sign design will enhance sign visibility at night, and will allow drivers longer legibility distances and greater reaction times, thus improving safety at night.

TRAFFIC SIGNS

Sign Requirements, Evaluation and Design

Traffic signs convey visual information to the road user. To perform this function effectively, traffic signs should meet several basic requirements. First, the sign should be capable of fulfilling an important need. Second, it should command attention or be easily detected by the person who needs the information. Sign features such as size, contrast, color, shape, composition, and lighting or reflectorization contribute to the attention-getting quality of a sign. Third, the sign should convey a clear and simple meaning, which is produced through the combination of shape, size, colors, and simplicity of message. The sign should also command the respect of road users, which is affected by uniformity, size, legibility, and reasonableness of the regulation. Fourth, the sign must be legible at the appropriate distance, it must be located to give adequate response time, and it must often be legible when seen for a very brief time (glance legibility). Finally, the sign must be sanctioned by law if it controls or regulates traffic. (U. S. Department of Transportation, 1983, 1993; Dewar, 1993)

Previous research (e.g., Dewar, 1988, 1989, 1993; Mace, 1988) and the basic requirements for a good traffic sign (U. S. Department of Transportation, 1983) have led to the suggestion that several criteria are important in evaluating and designing traffic signs. These criteria include:

- *legibility distance*, or the greatest distance at which the sign can be clearly "read;"
- *understandability*, or the ease with which a sign can be understood;
- *conspicuity*, or the extent to which a sign can be easily detected or seen in a visually complex environment;
- *learnability*, or the extent to which the meaning of a sign can be learned and remembered;
- *glance legibility*, or the ease with which the sign can be "read" when it is seen for only a fraction of a second; and
- *reaction time*, or how quickly the meaning of the sign can be identified.

The literature indicate that the following factors are important when considering the above criteria:

shape coding and sign size	letter fonts, size, and spacing
color coding and color combinations	conspicuity
understandability of symbols	uniformity of design
proximity of borders	luminance of the sign
illumination	retroreflectivity
environmental effects such as darkness	sign positioning
speed of motorist response to the sign	individual differences (e.g., age)
visual abilities	information overload

This list, although not comprehensive, demonstrates that there are many design issues that will impact the usefulness of a traffic sign.

Research efforts by Youngblood and Woltman (1971) led them to report that sign visibility and legibility are important factors in traffic sign design, especially with highway and safety problems developing with increasing traffic volumes. Traffic sign visibility is dependent upon detection, identification, and legibility of the sign. These factors are influenced by choice of legend, color and shape, sign size and position, materials, and lighting characteristics. Sign legibility is also affected by letter width, letter stroke width, spacing between letters, proximity of borders and other lettering, contrast between legend and background, and general level of brightness. In addition, the choice of sign materials impacts the potential benefits on sign visibility and legibility that may be produced by these factors.

Studies by Forbes (1939), Lauer (1932), Mills (1933), and Doughty (1982) have suggested three qualities that are most important to consider in traffic sign design: attention value, legibility, and recognition. Attention value is the characteristic of the sign that demands attention, and can be divided into two types -- target value and priority value. The former refers to the quality that makes a sign or group of signs stand out from their background, while the latter is the quality that makes it possible for a sign to be read first, in preference to others. These values are dependent upon relative size, color contrast of signs and background, sign brightness, relative position of signs (Doughty, 1982; Pain, 1969), and at night, reflectorization. The effect of background color is also important due to the effects that color may have on the attention, specifically target, value of signs. The second quality, legibility, can be defined as the characteristic of being readable, and may also be divided into two types. Pure legibility is the distance at which a traffic sign can be read under optimum conditions, i.e., with no distractions and in an unlimited time, and glance legibility is the distance at which a sign can be read under quick glance conditions. The third important sign quality is recognition, which can be defined as the characteristic of being recognizable and understandable through the use of standardized colors, shapes, and legends.

There are a number of components of sign design that are used to allow traffic signs to meet the basic requirements of a good traffic sign. The main components of sign design involve the overall size and design of the message. While sign legibility increases with sign size, the overall dimensions are generally standardized (i.e., specified by the MUTCD) for different highway types and will not be discussed here. Message design consists of trying to optimize the message size within the given sign dimensions to achieve the greatest legibility (Shepard, 1987). Minor modifications of the specified design elements may be necessary and are allowable, provided that the essential appearance characteristics are met. Attempts to investigate the different possibilities may include changes in letter series, letter height, message placement, and letter stroke width.

The design and placement of traffic signs are regulated by the MUTCD and state specifications. Standard and emergency detour signs feature a rectangular shape, with longer dimension horizontal, as is used for most guide signs and some warning signs. This standard shape in combination with a unique color coding scheme facilitates recognition of the sign even before the motorist is close enough to read the message. Borders provide further redundancy by emphasizing the information coded in the sign's rectangular shape, and previous research (i.e., Markowitz, Dietrich, Lees, and Farman, 1968) suggest that broader borders are better for conveying that shape information. In addition, standardized symbols, such as the arrow icon, can be interpreted quickly without the need to read a word message. Finally, signs are generally posted, via mounting on posts or portable supports, on the right-hand side of the roadway, but may be located on both the left and right sides when special emphasis is needed. (U. S. Department of Transportation, 1983)

Sign Reflectorization for Night Visibility

In addition to the basic components of sign design and placement described above, the MUTCD specifies that all signs intended to be used during hours of darkness shall be reflectorized with a material that has a smooth, sealed outer surface, or illuminated to show approximately the same shape and color day and night (U. S. Department of Transportation, 1983, 1993). Reasons cited by Doughty (1982) for this requirement include improvement of the attention-getting properties of the signs and preservation of color coding under night as well as day viewing conditions. Doughty suggested that an increase in the potential nighttime brightness of signs makes them as legible under night conditions as under day conditions, and provides good target value and legibility from the maximum to the minimum approach distance.

According to Doughty (1982), the combination of improved automobile headlighting and more effective reflecting materials during recent years has made reflectorized signs as effective as certain types of illuminated signs. Doughty suggested that signs of proper reflectivity provide satisfactory visibility under most driving conditions. A variety of sign background materials may be used to achieve the optimal level of nighttime sign visibility. Most current traffic signs are composed of one of a variety of highly reflectorized, or retroreflective, sheeting materials. These materials increase sign visibility at night by causing light rays from a vehicle's headlights that strike the surface of the sign to be redirected back toward the driver. This retroreflective characteristic is derived from minute glass beads embedded in a flexible plastic sheeting or from minute corner cubes molded in the surface of a plastic sheeting. To reflect colored light, pigment or dye is incorporated into the reflective coating material. (U. S. Department of Transportation, 1983)

Signs reflectorization is accomplished by reflectorizing the sign legend and border reflective; by reflectorizing the background; or by reflectorizing both legend and background (U. S. Department of Transportation, 1988; Doughty, 1982). Doughty (1982) noted that when only the sign legend is reflectorized, the letter stroke must be relatively wide and the reflectorization must have a high luminance so that adequate target value can be achieved. Where both legend and background are reflectorized, the legend should be provided with a higher brightness value than the sign's background material.

According to Doughty (1982), the reflective materials used in traffic signs must have a wide-angle response to reflect light even when the approaching vehicle headlights are well to one side of the sign. Doughty noted that good reflectivity at wide angles is required to: 1) produce good sign visibility over a long range of approach distances, including short viewing distance; 2) offset the effect of inaccuracies in sign installations; and 3) be of use on multilane roadways, where the lateral distance between passing vehicles and traffic signs may be considerable.

The luminance of a retroreflective sign depends on several factors, including the reflective efficiency of the material of which the sign face is constructed, as well as the intensity of the headlights of an oncoming vehicle. In addition, the distance of the light source from the sign, the position of the sign relative to the roadway, and the shape of the road approaching the sign are important (Olson and Bernstein, 1979).

Highway Sign Colors

The current specifications for highway colors include 12 highly saturated colors of medium to low lightness. These colors include red, yellow, blue, white, brown, black, orange, green, purple, light blue, coral, and brilliant yellow-green. The first eight colors listed are used for certain functions as specified by the MUTCD, while the latter four colors are not currently assigned for use in the United States (U. S. Department of Transportation 1969, 1988).

Color Coding

A review of studies on color coding indicates that color coding is effective and highly desirable for conveying simple, yet important information quickly and accurately, particularly under stressful conditions. This provides an effective means to make sure that important information is easily recognized by drivers (Collins, 1989; Christ, 1975; Cole and Vingrys, 1985; Green and Anderson, 1956; MacDonald and Cole, 1988). Further, studies have shown that color coding facilitates detection and recognition of warning messages, such as those conveyed by traffic signs, that appear unexpectedly and infrequently (MacDonald and Cole, 1988). The studies cited, however, also report that maximum effectiveness of color coding is only achieved when the drivers are familiar with the color coding scheme. A survey conducted by Ogden et al. (1990) illustrated this problem when they found that over 40 percent of the 205 respondents did not know the difference in meaning between yellow caution signs and orange construction signs, and only 44 percent knew that orange is the color designated for construction signs.

Another issue related to the effectiveness of color coding is the use of retroreflective materials and lighting. Lozano (1980) noted that the color of retroreflective signing materials will not be the same under both the diffuse viewing conditions of day and the directional viewing conditions of night. Color depends on the illuminant by which it is viewed as well as the viewing geometry. Viewing a sign under daylight or an artificial approximation of daylight yields what is considered “the color” associated with the object (Chamberlain and Chamberlain, 1980). Nighttime viewing conditions are dependent upon lighting from headlights and external light sources, as well as the geometry of lighting and viewing, and result in a lower level of visibility. Under these degraded conditions, drivers with reduced color perception and color deficiencies may find it more difficult to determine the actual color of some retroreflective signs. However, upon a review of studies investigating color perception at night, Gordon (1984) concluded that while color perception is weaker at night than during the day, drivers are able to identify colors under night driving conditions.

Letter Stroke Width

The state of Virginia currently employs diamond grade reflective sheeting on many of its traffic control signs; however, the highly reflective nature of this sheeting material may result in irradiation, which causes problems with sign legibility. Irradiation causes black letters to appear smaller (which MUTCD does not take into consideration), in which case larger or wider letters may improve legibility. On the other hand, white letters on a dark background appear larger; in this case, a narrower stroke width would be needed to counteract the effect of irradiation (Allen and Straub, 1955). Decreasing the influence of irradiation involves two procedures: increasing letter size by increasing the letter series and/or height, and increasing or decreasing the letter stroke width (i.e., how thick the lines of the letter are) as appropriate (Shepard, 1987).

Research efforts by Hind, Tritt, and Hoffmann (1976) and Kuntz and Sleight (1976) have investigated the effects of varying stroke width. Hind et al. (1976) studied, among other elements, five stroke widths and concluded that “for black numerals the strokewidth/height

(SW/H) interacts with the visual angle and the greatest legibility is for SW/H = 0.167" (or H/SW = 5.98). Kuntz and Sleight (1976) conducted a study to establish an optimal ratio between letter height and stroke width. They concluded that the optimal ratio between letter height and stroke width (H/SW) is approximately 5.0 (SW/H = 0.2). These research efforts indicate that for black lettering on bright reflective sheeting, increases in letter stroke widths give better legibility (Shepard, 1987).

Zwahlen, Sunkara, and Schnell (1995) reported similar findings when they conducted a study to compare and consolidate past legibility research for the purpose of obtaining normalized legibility performance data. They concluded that while the recommended SW/H ratios varied considerably among the studies they reviewed, it was generally found that dark characters displayed on a light background require smaller stroke widths than light characters displayed on a dark background.

Since the MUTCD design standards have already optimized the letter/message size and spacing to fit most signs, any modification of letter stroke width would involve widening the stroke width without altering the letter width or height. Shepard (1987) noted that studies conducted in Nebraska around 1975 using encapsulated sheeting resulted in the decision to compensate for loss of legibility by increasing stroke width approximately 20%; the letter width and letter spacing were not modified. This required that the stroke width be widened to the inside of the letter. Shepard recommended that a similar strategy be implemented in Virginia, and suggested an increase of approximately 18% in letter stroke width. To implement these modifications, the letter stroke width would be increased or decreased to the inside only so that the letters occupy the same rectangle of space.

Contrast

Studies by Forbes, Fry, Joyce, and Pain (1968) indicate that signs seen "first and best" must have good contrast within the sign, i.e., between the legend and the background, and good contrast with the surrounding environment. Contrast can be defined and calculated in several ways, with the three types of interest relative to sign visibility and conspicuity being color contrast, luminance or contrast ratio, and luminance contrast.

Color contrast refers to the perceptual difference in two adjacent colors, is related to traffic sign conspicuity, and is of primary importance during daylight driving conditions. Researchers note, however, that this color difference equation can only be expected to provide approximate predictions of conspicuity due to its lack of uniformity over the large regions of color space to which it is applied. It has been shown that color difference may have potential as a predictor of conspicuity, and that color difference may have applicability as a general predictor of contrast (Carter and Carter, 1981). As such, the 1976 CIE L*u*v* distance between visible color stimuli can be employed to determine color distances and to provide a mathematical prediction of perceived color contrasts, for either equal or unequal brightness stimuli (Post, Costanza, and Lippert, 1982). The C.I.E. recommends the use of dL*u*v* to achieve uniform spacings for objects that feature large chromatic differences, such as those proposed for this study (Post, 1983). Other researchers (Post, Costanza, and Lippert, 1982; Post, Lippert, and Snyder, 1983;

Post, 1983) suggest, however, that while the 1976 CIE L*u*v* space is useful, it is not perceptually uniform.

Contrast ratio and luminance contrast refer to differences in lightness, i.e., light reflected from the object, between two adjacent colors, and is of primary importance during nighttime driving conditions. The values for contrast ratio and luminance contrast are defined by the following:

$$\text{Contrast ratio, } C_R = L_{max}/L_{min}$$
$$\text{Contrast, } C = (L_{max} - L_{min})/L_{min}$$

where L_{max} = luminance value of the brighter of two contrasting areas, and L_{min} = luminance value of the darker of two contrasting areas.

Richards (1966) conducted a study investigating visual ability to discriminate letters rather than sign legibility distances. His results yielded average values that indicated the need for over 40 to 50 percent contrast for day luminance, and 50 to 60 percent contrast under night driving luminance levels. He also reported that, on average, older participants demonstrated a greater need for high contrast targets.

In a review of literature on the night visibility of overhead guide signs, Gordon (1984) noted that sign legibility is dependent upon legend luminance and the amount of legend to background contrast. The level of brightness of the environment surrounding the sign also affects legibility. He suggested that under low levels of illumination, as in typical ambient rural conditions, optimal legend luminance is approximately 34 candelas/meter^2 (cd/m^2) (10 Footlamberts) with a minimum value of 3.4 cd/m^2 (1 Footlambert). Legend to background contrast ratios of 10:1 or higher are usually recommended. Under very dark conditions, the luminance ratio of the sign legend to a black sign background may be as high as 100:1 or more. Gordon noted that specification of the legend luminance is more meaningful than that of contrast ratio under such circumstances. Under high levels of illumination, Gordon noted that the legend may be as bright as 102 cd/m^2 (30 Footlamberts), and the legend to background contrast ratios should be 4:1 or higher for satisfactory visibility. For the latter case, Gordon noted that the legend will irradiate and sign legibility will be reduced if the contrast between legend and background is too high.

Forbes et al. (1968) reported that signs seen “first and best” must have good contrast within the sign and good contrast with the surroundings. Sivak and Olson (1985) noted that studies relevant for the situation where only the background luminance is appreciably greater than 0, i.e., black legend on a light background, indicate that the recommended optimal luminance of a white, orange, or yellow background with a black legend is 75 cd/m^2. For a light legend on a dark background, Sivak and Olson (1985) noted that the optimal retroreflectance of one component (legend or background) depends on the given retroreflectance of the other component. Their recommended optimal legend-background contrast for fully reflectorized signs is 12:1. For example, if the background luminance is 1 cd/m^2, the optimal luminance of the legend should be 12 cd/m^2 (Sivak and Olson, 1985). Olson and Bernstein (1977) found that luminance contrast requirements are lowest for highly reflective backgrounds and increase as background reflectivity decreases.

Conspicuity

Cole and Hughes (1984) suggested that conspicuity refers to "the property of an object that causes it to attract attention or to be readily located by search." They divide conspicuity into attention conspicuity and search conspicuity. The former refers to the capacity of an object, or sign, to attract attention; Cole and Hughes suggest that attention conspicuity may be measured by the probability that an observer will notice the sign without prior notice of the sign's occurrence in the field of view. Search conspicuity refers to the capacity of a sign to be located "quickly and reliably" when the observer is searching for the sign. Cole and Hughes presented a review of the literature on this topic and noted several ways of measuring search conspicuity; however, they also noted that the task in each method requires that the observer direct his or her attention to locating the sign.

The conspicuity of a sign is dependent upon characteristics of the sign and of the environment in which it is used. Jenkins and Cole (1986) found that the important sign-related variables that determined daytime conspicuity are the sign size, its contrast with the immediate surroundings, and the complexity of the background. They suggest that the present size of road signs (400 to 900 mm) is sufficient to ensure that the signs are conspicuous. They concluded that a sign is not conspicuous due to insufficient contrast within the sign itself, to a high degree of visual clutter, or a combination of both. Van Norren (1981), however, suggested that the conspicuity value of a traffic sign is not derived exclusively from properties of the traffic sign itself, but is affected by characteristics of the environment. He cited location of sign placement, driver expectations, and frequency of occurrence of the sign as important contributing factors.

Researchers have also investigated the effects of sign color on sign conspicuity and have reported mixed results. Olson (1988) found that while colors such as red, green, and blue may have reduced luminance as compared with yellow, there is little or no loss of conspicuity for these colors. Olson concluded that until more precise data on the effect of color becomes available, it would be assumed that all colors within a given family of materials are as effective as yellow. Studies by Forbes et al. (1968) and Olson and Bernstein (1979), among others, demonstrated similar findings; these researchers concluded that color contrast has little effect on detection distance. The results of these studies indicate that detection differences among colored signs are attributable to luminance contrast.

Jenkins and Cole (1979) suggested that color is not an important contributor to sign conspicuity and that, at best, color serves to offset the loss of conspicuity that results from the decrease of luminance that occurs when using a color other than white. However, Jenkins (1982) showed that contrast is critical to sign conspicuity and the presence of color contrast may serve to reveal an object when the luminance contrast is low.

Olson (1988) investigated the effects of sign legends and borders on overall sign brightness and nighttime conspicuity of highway signs. Sign colors ranged from light, including yellow, orange, and white, to dark, including red, green, and blue. The study demonstrated that for light-colored signs, such as yellow, orange, and white, use of black borders and legends reduced sign conspicuity by reducing overall sign brightness. This effect was most significant at longer distances, where the sign approximated a point source. Olson recommended increasing the retroreflective efficiency of the sign materials to compensate for this loss. The darker red, green, and blue signs featured white borders and legends, which nominally improves conspicuity by increasing sign brightness. The field data indicated that the benefits of the colored background outweighed the contribution of the white legend and border, and thus no recommendations were made regarding retroreflective efficiency for the darker signs.

Legibility

Legibility is one of the most important qualities of traffic signs and was adopted in an early study by Forbes (1939) to indicate ability to read the letters on a sign. Forbes considered two types of legibility -- pure legibility and glance legibility. The former refers to legibility under optimum conditions, i.e., with no distractions and unlimited reading time, while the latter refers to legibility under quick glance conditions, or when reading time is limited. Other sign qualities that interact with legibility to affect a driver's ability to detect, identify, and read a sign are attention value and visibility.

Forbes (1972), Olson and Bernstein (1977), and Zwahlen et al. (1995) provide extensive reviews of the literature regarding studies of the factors affecting sign legibility, including subjective evaluations of various sign treatments, the effects of luminance and contrast on legibility, and the use of mathematical models to predict sign luminance and/or legibility. The literature indicate that the most important factors for sign legibility include but are not limited to letter height, letter height-width ratio, letter stroke width, character width, letter contrast , the spacing between the letters and words, and the vertical spacing between lines of text, as well as possible interactions between these factors.

Many studies have investigated optimal legibility distance as it relates to letter design. Forbes and Holmes (1939) noted that the rule of thumb used at the time by sign designers gave 50 feet of legibility distance per inch of letter height. The results of a study by Forbes and Holmes investigating the relationship between legibility distance and letter height, letter width, and reflectorization showed a good correspondence to this rule for wider black on white series D letters (as compared to narrower series B letters) under day conditions, but roughly 15 percent shorter distances than this for night conditions. Similar results were obtained by Forbes, Moskowitz, and Morgan (1950), who compared legibility distances of lower-case and capital letters using both familiar and scrambled letters, but they found that familiar words yielded longer distances. Forbes et al. (1950) found that the normal or 20/20 legibility distance for scrambled capital letters was approximately 55 feet per inch of letter height, while familiar words yielded approximately 65 feet per inch. They noted, however, that the distances "showed the effect of familiarity but should not be used as design standards for the general public since most states require only 20/40 vision." A later study by Forbes (1972) recommended that signs be designed to provide a legibility distance of 60 feet per inch, using a stroke width 20 percent of letter height, which together corresponded well with the usually accepted figure of one minute of arc for normal (20/20) visual discrimination. Forbes noted again, however, that most states require only 20/40 vision for a driver's license.

Allen and Straub (1955) studied the effects of different levels of sign brightness on sign legibility. They found that legibility distance was a function of letter series and sign brightness. Their work showed that as the size of the letters increased (from Series A to Series F), the sign legibility distance increased for each level of observed brightness. They concluded that the primary reason for this increase was that the letter size increases in width and letter stroke width as the series changes from A to F.

The practical problem that road researchers and traffic engineers have been studying for years is whether a sign attracts enough attention to be read when it is within legible distance. Providing good sign legibility is important, especially for signs used to warn drivers of existing or potentially hazardous conditions. Shepard (1987) noted that sign legibility can be increased for bright sign materials by modifying the letter design. Letter modifications are permissible through the MUTCD, especially if standardized MUTCD designs are used. Shepard suggested that "providing good legibility for signs necessary to warn drivers of existing or potentially hazardous conditions is certainly desirable, and if sign modification can help the traffic engineer achieve this goal, it should be considered."

Legibility under Nighttime Viewing Conditions

The legibility of traffic signs, in addition to the conspicuousness or visibility of signs, is as important under nighttime viewing conditions as under day conditions. Olson and Bernstein (1979) suggested that the most critical factors for sign legibility at night include the size of the legend, contrast between the legend and its background, and luminance of the background. Hind et al. (1977) suggested that stroke-width and the direction of the luminance contrast are also critical for nighttime legibility of signs.

Many researchers, including Shepard (1987), have suggested that irradiation is at least partially responsible for sign legibility problems. Case, Michael, Mount, and Brenner (1952) reported that for relatively bright sign materials, irradiation caused an apparent decrease in the spacing between letters. Allen and Straub (1955) examined the relationship between sign brightness and legibility by comparing a message of the same size and same letter series at optimum and high brightness. The results of their research showed that black letters on a white background appeared narrower, and white letters on a black background appeared fatter at high brightness, which resulted in a reduction in legibility. In addition, Shepard (1987) suggested that when traffic signs are close to the highway, as may be the case for warning signs or signs placed in conjunction with work zones, the amount of light striking the face of the sign from passing vehicles can reach levels that result in very high background luminance, thereby causing irradiation and a consequent decrease in legibility.

Among the environmental factors affecting sign legibility at night, Schrober (1967) found that the effects of glare are of interest due to known glare effects on detectability and contrast sensitivity. Among participant characteristics, the effects of age are of concern because of known age effects on visual acuity and other visual capabilities.

Legibility and Age-Related Differences

Research studies (Olson and Bernstein, 1977; Sivak, Olson, and Pastalan, 1981; Chrysler, Danielson, and Kirby, 1996) have shown that younger drivers were capable of discriminating signs at greater distances than older drivers despite equivalent high-luminance visual acuity. The findings suggest that the older driver has to come to a traffic sign in an actual driving situation in order to be able to read it closer, specifically to a distance ranging from 65 to 77% that of younger drivers. As a result, the older driver tends to have less distance and time in which to interpret and act on the information contained in the sign.

Evans and Ginsburg (1985) found that highway sign discrimination distance was significantly related to contrast sensitivity and not visual acuity. Their study found that older and younger drivers matched in visual acuity differed greatly in contrast sensitivity. In fact, older drivers had significantly lower contrast sensitivity than younger drivers at three spatial frequencies, and required significantly larger sign symbol for sign discrimination, which translates into greater discrimination distances.

Research by Sivak and Olson (1982), however, indicated that there was no age-related effect in nighttime legibility distances when younger and older drivers are matched in terms of their low luminance/high contrast acuity and high luminance/high contrast acuity under the test conditions. According to Sivak and Olson, these findings implied that the usually observed age-related decrement in nighttime legibility performance was due exclusively to the deterioration of visual acuity and not to any information processing deficits.

Consideration of all of these results leads to one basic conclusion: reliance on legibility distance data obtained from younger participants for establishing sign standards is likely to be insufficient in providing adequate legibility for older drivers. Thus, legibility standards should not be based exclusively on the data obtained from younger participants, but should instead consider the range of participant abilities.

Environmental Effects and Degraded Visual Conditions

Environmental effects, such as those caused by rain, dew, fog, and frost, as well as deterioration caused by the sun and weather, may reduce sign reflectorization effectiveness. Both the roadway and traffic signs are less visible under these conditions. Other sources of degradation in the reflective properties of traffic signs include road dirt, exhaust residuals, water spray, etc. from passing vehicles (Shepard, 1987). While these effects are important factors relative to sign identification and recognition, study of these effects is beyond the scope of this research effort.

SUMMARY

Previous research indicates that there are many factors, including driver limitations and abilities, physiological factors associated with the aging process, differences between day and night viewing conditions, letter and color design parameters, and fabrication and design of signs, that influence the effectiveness of traffic control signs, and there are many experimental measures that can be used to evaluate traffic signs. Sign legibility has been used more than any other measure for the purpose of evaluating sign effectiveness. As noted by Gordon (1984), legibility lends itself readily to research investigation and statistical interpretation, and the proof that an experimental participant has read a traffic sign message can be unequivocally demonstrated by checking the response against the actual letter, word, or message displayed on the sign face. Objective measures of conspicuousness and how quickly and clearly a message is understood also provide effective means for evaluating the adequacy of a traffic control sign (Monty, 1984; Dewar, 1993).

CHAPTER 3. METHOD, RESULTS, AND DISCUSSION OF LEGIBILITY EVALUATION OF SIGN DESIGN PARAMETERS

This research was conducted in two parts, the first of which is presented in this chapter. Study 1 included the specification of the sign configurations of interest and an off-road field study investigating the legibility of the specified sign configurations. The results of this initial study were used to guide selection of sign color and letter design parameters for further investigation in the second part of this research, an on-road field study of conspicuity and understandability, hereafter referred to as Study 2.

METHODOLOGY

General Approach

To examine the legibility of the sign colors of interest, the design specifications for 27 sign configurations were developed, and an off-road field study was conducted to investigate the legibility of the various sign configurations based on sign design, observer age, and visibility condition.

Experimental Design

The assignment of participants is shown in Table 1. Male and female participants in two age groupings, younger and older, were randomly assigned and were divided approximately equally between two visibility conditions, day (clear and cloudy) and night. All participants were shown all 27 test signs, representing combinations of 13 sign color combinations, 2 letter heights and 2 letter series, and each participant was exposed to one viewing condition (day clear, day cloudy, or night), as indicated in Table 1. Furthermore, presentation of the signs was counterbalanced to account for the position of the sun in reference to the sign.

Table 1. Experimental assignment of participants in Study 1.

	Younger Participants			Older Participants			
Test	**Day**		**Night**	**Day**		**Night**	
Signs	**Clear**	**Cloudy**		**Clear**	**Cloudy**		
#1-27	4*	1*	4*	3**	1	3	
	5		4	4		3	**Total**
Totals	9			7			16

*Includes participant with known color vision deficiency.
**Includes 42-year old male with known color vision deficiency and participant with previously unknown color vision deficiency.

Independent Variables

The independent variables in this experiment included the following:

Sign color and contrast. The test signs included 13 color combinations; these combinations represented the color pairings that yielded the greatest luminance and/or color contrast values using standard highway sign colors. The color combinations featured standard highway orange in the background, as well as the previously unassigned traffic sign colors of coral, light blue, purple, and brilliant yellow-green. The first color combination included the standard orange background with black legend. The next 11 combinations, background and legend, were as follows: 1) coral and black; 2) coral and blue; 3) coral and white; 4) light blue and black; 5) light blue and blue; 6) light blue and yellow; 7) purple and black; 8) purple and white; 9) purple and yellow; 10) brilliant yellow-green and black; and 11) purple and brilliant yellow-green. The final color combination featured two background and legend color combinations -- white with red letters and blue with white letters. This color combination represented the red, white, and blue sign currently under consideration in Northern Virginia. The color combinations (background and legend) were chosen based on analyses of luminance contrast and color contrast. The data collection and calculations are described in the Procedure section.

Sign letter stroke width. The stroke width ratio values were 14 mm (0.55 in) and 16 mm (0.63 in). The corresponding stroke width values range from 14 mm (0.55 in) to 20 mm (0.79 in), depending on the letter series, C or D, and letter height, 100 mm (4 in) or 125 mm (5 in), as specified in the *1977 Metric Edition Standard Alphabets for Highway Signs and Pavement Markings* (U. S. Department of Transportation, 1982). Note that "letter series" is used in place of "letter stroke width ratio" in the analyses described in this document.

Sign letter height. The two letter height values of interest were 100 mm (4 in) or 125 mm (5 in). These values were chosen based upon the letter heights used on the current standard EMERGENCY DETOUR sign. The letter heights for the upper and lower legends on the current sign standard are 100 mm (4 in) and 125 mm (5 in), respectively.

There is one exception to this specification. The letter height of interest for the red, white, and blue test signs was limited to 100 mm (4 in). This allowed the parameters of the test signs to match a red, white, and blue test sign proposed for use in Northern Virginia.

Age. Two age groups of participants were used: younger participants (18-25 years) and older participants (65-75 years). Since vision under low visibility conditions was of particular interest to the study, the naturally occurring age-related changes in the visual system were of primary interest.

Visibility condition. Daytime versus nighttime conditions were tested. Participants observed the test signs on one occasion, for approximately two hours, under one of three viewing conditions. The conditions consisted of the following:

1. Daytime. This viewing condition was subdivided into clear and cloudy conditions for the purposes of data collection, however, data collected for these two subdivisions was combined for the purposes of data analysis. The daytime viewing condition consisted of the following:

a. Clear. A total of six (6) participants observed the test signs during daytime sessions when the sky was clear. Morning test sessions began no sooner than one hour after sunrise, and evening test sessions ended no later than approximately one hour before sunset. All data collection occurred in fair weather, i.e., no precipitation was falling.

b. Cloudy. A total of three (3) participants observed the test signs during daytime sessions when the sky was overcast with cloud cover. Test sessions began no sooner than one hour after sunrise. All data collection occurred in fair weather, i.e., no precipitation was falling.

2. Nighttime/Low headlights. A total of seven (7) participants observed the test signs during nighttime sessions, with only the low beam headlights of the test vehicle to illuminate the test signs. Test sessions began no sooner than one hour after sunset. All data collection occurred in fair weather, i.e., no precipitation was falling.

Controlled Variables

The controlled variables included gender, level of color vision deficiency, and time of day at which the experimental session was conducted.

Gender. Gender was controlled such that an approximately equal number of male and female participants were assigned and tested under day and night visibility conditions. A total of three female and three male participants within the younger and older participant groups observed the test signs during daytime sessions. Four female and two male participants within those same participant groups observed the test signs during nighttime sessions. All four of the participants in the color vision-deficient participant group were males since no female participants with known color vision deficiencies were available for participation.

Color Vision Deficiency. Visual ability was controlled such that four of the participants were known to have, and demonstrated, some level of red/green color vision deficiency. In addition, one older male participant demonstrated a color vision deficiency, but he was not previously aware of the deficiency. This participant was included among the older participants.

Time Of Day. Daytime subjects participated during the morning (8:30 AM to 11:00 AM) or the evening (6:00 PM to 8:00 PM, with one subject from 4:00 to 6:00 PM) hours of the summer season (June/July, 1997). This was to control for the spectral property differences between the morning and evening sun.

Dependent Variable

Legibility Distance was the dependent variable. Three distance measures were collected for each test sign. These distance measures (recorded in meters from the sign) included: 1) the distance from the test sign at which the participant was able to read the top text legend; 2) the distance from the test sign at which the participant was able to read the bottom text legend; and 3) the distance from the test sign at which the participant was able to identify the direction of the arrow icon.

Participants

Sixteen subjects participated in Study 1. Six participants were between the ages of 18 and 25 years (younger participants), and six participants were between the ages of 65 and 75 years (older participants). The remainder of participants, with ages ranging from 23 to 42, demonstrated known red/green color vision deficiencies, and age was not considered in selecting these participants. Refer to Appendix A for a detailed description of the participants. Younger participants were recruited through flyers posted on the Virginia Polytechnic Institute and State University campus. Older participants were recruited through retirement communities and flyers posted at local merchants. All participants received $23 for participating in this study for approximately two hours of experiment time.

Each participant was required to: (1) be a licensed driver; (2) drive a minimum of twice a week in Blacksburg, Virginia, or the surrounding area; (3) pass a health questionnaire; and (4) have a minimum 20/40 visual acuity, wearing corrective lenses if necessary. In addition, a subset of participants had to demonstrate a previously identified color vision deficiency.

The data for one young, female subject who participated at night was not used in the final data analysis. Due to the fact that she wore contact lenses that were not her normal corrective lenses, she demonstrated an above normal difficulty in reading the signs, which resulted in significantly shorter reading distances than those obtained for the other younger participants within the nighttime test condition.

Apparatus

Sign legibility distance was investigated on an isolated test strip using a 1995 Oldsmobile Aurora four-door sedan. The primary apparatus used to determine the sign design configurations of interest in the first study included the following: (1) Minolta CS-100 chroma meter; (2) Illuminance meter; (3) Macbeth® Spectralight® II lighting booth; and (4) software and hardware interfaces for data collection and analysis. The primary apparatus used in the field study investigating legibility distance included the following: (1) automobile; (2) software and hardware interfaces for data collection and analysis; (3) Optec 2000 Vision Tester for acuity and color vision screening; and (4) the 27 test signs featuring a range of color combinations (based on predetermined background colors and luminance and brightness contrast measurements and calculations) and letter stroke widths.

Minolta CS-100 Chroma Meter

The Minolta CS-100 tristimulus color chroma meter was used to obtain non-contact luminance measurements (chromaticity values in Yxy) of the color samples used to develop the test sign design specifications.

Illuminance Meter

A Minolta T-1 illuminance meter was used to obtain initial illuminance measurements of the lighting conditions used to develop the test sign design specifications. The measuring range for this device is 0.019 to 900 lx (0.001 to 990 ft-c). An Extech Instruments Digital Light Meter will be used to obtain illuminance measurements near the test signs during the various data collection sessions in Study 1. The measuring range for this device is 0.0 to 50,000 lx (0.0 to 5,000 ft-c).

Macbeth® Spectralight® II lighting booth

The Macbeth® Spectralight® II lighting booth was used to simulate a typical daylight viewing condition for color samples during the development of test sign design specifications. The lighting booth was used to produce an average day lighting condition of 565 lux (measured vertically, i.e., parallel to the color sample). In addition, the darkened booth was used in combination with a darkened laboratory and a 150-watt reflector incandescent bulb located approximately three meters from the booth to simulate two night-viewing conditions. These conditions will be described in the Procedure section.

Optec 2000 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, however, it was not able to classify as to type.

Automobile

A 1995 Oldsmobile Aurora was used as the observation vehicle for all participants. The low-beam halogen headlights were used during night driving conditions. In addition, the vehicle’s windshield was cleaned prior to each testing session.

Safety Requirements

The following safety measures were provided as part of the vehicle system to minimize risks to participants during the experiment:

1. The test vehicle was driven in an area not in contact with other traffic.

2. The experimenter, not the participant, drove the vehicle, and was responsible for driving in a safe and legal manner. This technique allowed to participant to concentrate on reading the sign.

3. Participants were required to wear the lap and shoulder belt restraint system while in the car. The vehicle was equipped with a driver's side and passenger's side airbag supplemental restraint system.

4. The vehicle was equipped with a fire extinguisher, first-aid kit, and a cellular phone, to be used in an emergency.

5. If an accident were to occur, the experimenters would arrange medical transportation to a nearby hospital emergency room. Participants would be required to undergo examination by medical personnel in the emergency room.

Software and Hardware Interfaces for Data Collection

The distance from the sign was measured (in feet, ft) through the data acquisition system in the instrumented vehicle. The system converted odometer pulses to feet and displayed this information on a display for the experimenter to read and copy onto paper. After collecting data for each sign, the display was reset to zero by depressing a button installed for that purpose. The system was calibrated to within 1.32 ft (15.84 in, or 40.23 centimeters).

The data for this experiment were collected manually, and were entered into a microcomputer for analysis. The data were entered into a spreadsheet/statistical data sheet format for analysis and archival purposes.

Test Signs

There was 27 test signs featuring 13 color schemes and four legend designs. Each sign had a unique color, contrast, stroke width, and two-part word combination. These unique combinations are specified in Appendix B. The test signs were 0.609 m (24 in) tall by 0.762 m (30 in) wide, similar to the standard Emergency Detour sign currently used. An exception was a red, white, and blue Emergency Detour test sign which was 0.609 m (24 in) tall by 0.914 m (36 in) wide. This larger size was necessary to accommodate the use of series D letters for the upper legend, “Emergency,” if the standard distance between letters was not to be compromised.

The color combinations, background and legend, included: 1) orange and black; 2) coral and black; 3) coral and blue; 4) coral and white; 5) light blue and black; 6) light blue and blue; 7) light blue and yellow; 8) purple and black; 9) purple and white; 10) purple and yellow; 11) brilliant yellow-green and black; 12) purple and brilliant yellow-green; and 13) white with red letters and blue with white letters on the same sign. The correct Commission International d’Eclairge (CIE) Notations for these colors are provided in Appendix D as specified in the *Standard Highway Color Specifications* (U. S. Department of Transportation, 1969). Although close in notation, the coral color specified is not the same as that in the *Standard Highway Color Specifications* (U. S. Department of Transportation, 1969). The reason for the discrepancy is that the specified coral ink was not readily available from the manufacturer. The coral-colored ink specified for this study, as well as the purple-, light blue-, and brilliant yellow-green-colored inks, were specially formulated for this study.

The background colors for all of the test signs were fabricated by traditional silk screening, using colored inks, specifically Scotchlite™ Transparent Process Color by 3M, applied to aluminum sheeting via the 3M Company’s Scotchlite™ Diamond Grade Reflective sheeting material. The diamond grade sheeting material, which can be distinguished by the diamond-shaped lattice separating the sheeting layers, reflects back to the driver a maximum amount of light from vehicle headlights at a wide angle. The benefit of using diamond grade sheeting is two-fold: 1) it improves the conspicuity of the sign for both day and night conditions, and 2) it improves the conspicuity of signs that are slightly off angle, which is often the case in realistic work situations in which the worker’s must rush to get the emergency signs in place.

The legends and borders were applied to the test signs in one of several ways, depending on the color. All black legends and borders were applied using non-reflective black tape. All highway yellow legends and borders were applied using yellow-colored Scotchlite ™ Diamond Grade Reflective sheeting tape. White, blue, and brilliant yellow-green legends and borders were fabricated by traditional silk screening. Finally, the red, white, and blue signs featured red letters made from red Scotchlite™ Type III High Intensity Grade sheeting tape, which is distinguished by a hexagonal lattice or “honeycomb” appearance.

The test legends were composed of two parts, an upper (or first line) and a lower (or second line) legend. The first line legend letter series used in this study was series C or D. The letter height for the top row of characters (i.e., EMERGENCY in the standard sign) was the current standard of 10.0 cm (4 in) or the tested height of 12.7 cm (5 in). The word or words chosen for the first line legend were intended to have the same geometric shapes as the all-capitalized word “EMERGENCY.” The text, letter series, and letter height for the first line of legend to appear on each sign is specified for each sign number in Appendix B. The second line legend was either series C or series D. The letter height for the bottom row of characters was either the current standard of 12.7 cm (5 in) or the tested height of 10.0 cm (4 in). The word or words chosen for the first line legend were intended to have the same geometric shapes as the all-capitalized word “DETOUR.” The text, letter series, and letter height for the first line of legend to appear on each sign are specified for each sign number in Appendix B.

Details regarding the development and specification of the test signs are presented in Appendices B through I.

Sign Support Mechanism

Each sign panel was supported on a 7-foot-tall post, and was oriented approximately perpendicular to the direction of travel, facing the observation vehicle, as is normal practice. Sign panels were mounted such that the bottom edge of each sign panel was 1.52 m (5 ft) above the roadway, as specified in the MUTCD. The sign support mechanism was located on the right shoulder of the road, approximately 3.66 m (12 ft) from the edge of the travel lane, as specified by the MUTCD.

Procedures

Participant Screening and Training

Participants were initially screened over the telephone regarding age, gender, driving frequency, and general health (Appendix J). If participants met the experiment criteria, they were scheduled for testing. Participants were instructed to meet experimenters at the Center for Transportation Research (CTR) in Blacksburg, Virginia. After arriving at the CTR, the participant was given an overview of the study, and he or she was asked to review and complete the informed consent form (Appendix K). Next, he or she was asked to complete the health screening process (i.e., complete part 2 of questionnaire, Appendix J). In addition, he or she was given a simple vision test and a color vision test (Appendix L) using the Optec 2000 Vision Tester.

After these tasks were completed, the participant was escorted to the test vehicle in the parking lot of the CTR. While the vehicle was in park, the experimenter informed the participant that the purpose of the data collection session was to collect sign legibility distance data, or the distance at which the participant was able to read the sign legend. The experimenter then explained the test instructions and procedures to the participant (Appendix M). The experimenter then drove the participant from the CTR to the adjacent test site.

Test Facility

The study was conducted on an isolated test strip at the Virginia Tech airport in Blacksburg, Virginia. The test strip was approximately 4.6 m (15 feet) wide and 296.7 meters (970 feet) long, and was straight and flat. The sign posts used to support the test signs were positioned at the southwest (SW) and northeast (NE) ends of the test strip. There were few sources of illumination on or near the facility, and the test strip was generally dark at night, with limited external lighting located away from the tarmac.

Data Collection Techniques

The data for this experiment were collected manually, and were entered into a microcomputer for analysis. The data were entered into a spreadsheet/statistical data sheet format for analysis and archival purposes.

The data collection technique that was used is described as follows. The experimental protocol required three experimenters as well as the participant. Instructions were read to the participant, and the participant was given an opportunity to ask questions about the procedure. After all questions were answered, one practice run was given. Trials started immediately. At the test site, a 302-m (1,000 ft) strip of tarmac was marked off with traffic cones. The first and second experimenters were positioned at opposite ends of the test strip to mount and change the test signs (divided equally between them) according to a predetermined order of presentation. The third experimenter (the driver) was in the driver's seat, and the participant was seated in the passenger seat (with seatbelt fastened). The vehicle was positioned at one end of the test strip. The driver drove the vehicle toward the mounted test sign at 5 mph. (Note that the same experimenter drove the test vehicle during all test sessions.) When the participant indicated that he or she was able to read the test sign and to identify the direction in which the arrow was pointing, the driver stopped the vehicle and asked the participant to read the sign. The driver compared the participant's response with a prepared data sheet. If the participant read the sign correctly, the third experimenter recorded the distance to the sign using a computer-based system for recording distance data within the vehicle. If the participant was unable to read the sign correctly, the driver continued to drive toward the sign until the participant indicated that he or she was able to read the sign, and a legibility distance was recorded. After each trial, the car was repositioned for the start of the next trial, and the participant was asked to evaluate the previous test sign design by rating sign readability on a 5-point scale from not readable to extremely readable and by providing any further comments regarding subjective preference. This process continued until all test signs were tested.

There were a total of 27 test signs, which meant that each participant was asked to participate in 27 trial runs. Participants also participated in two practice runs. A pilot test was conducted prior to the data collection sessions to determine the exact time requirements and to coordinate the activities of the experimenters. A single trial run required approximately two to four minutes. As a result, the overall data collection process for each participant lasted up to two hours.

The order in which the sign variables were presented was varied systematically to compensate for order effects. The test signs were randomly assigned to one of two groups. Each group of signs was presented at either end of the test strip an equal number of times, and the order of sign presentation within each group was varied systematically (see Appendix N).

Photometric measurements of ambient light and reports of weather conditions were also recorded during each testing session (see Appendix O).

Debriefing

Following completion of the final test run, participants were driven back to the Center for Transportation Research, paid, and debriefed.

RESULTS

All statistical analyses were conducted using the SAS® 6.12 software package. Due to missing or unbalanced amounts of data (typical of field experiments), all analyses of variance (ANOVAs) were conducted using the general linear model (GLM) procedure (Littell, Freund, and Spector, 1991). In addition, given the available data and the goal of this study, which was to identify the sign color combinations and letter design parameters that resulted in greater legibility distances *overall*, the data analyses were restricted to main effects and lower order interactions as appropriate. For this experiment, a 0.05 significance level was used (95% probability that the results reported reflect actual differences). Post-hoc analyses were completed using the Student-Newman-Keuls (SNK) multiple range test to test main effect means; means with the same letter were not significantly different.

Legibility Distance Data

To the maintain statistical power of the experiment despite unbalanced cells, six data subsets were created from the legibility distance data. These subsets allowed the analysis of selected factors as part of the experiment. The results are presented as assessments of those data subsets in terms of: 1) overall sign color; 2) sign color with arrow icons only; 3) sign color and letter design; 4) visibility condition; and 5) participant age. Table 2 shows the data subsets and the associated factors of interest.

Table 2. Assessment of legibility distance data - data subsets and associated factors.

Subset	Factors
1. Overall Sign Color - All Participants, Day and Night	Sign Color
2. Arrow Icons Only - All Participants, Day and Night	Sign Color
3. Text Legends Only - All Participants, Day and Night	Sign Color, Letter Height, Letter Series
4. Visibility Condition - All Participants	Sign Color, Visibility Condition
5. Participant Age Classification - Day and Night	Sign Color, Age

Assessment For Sign Color

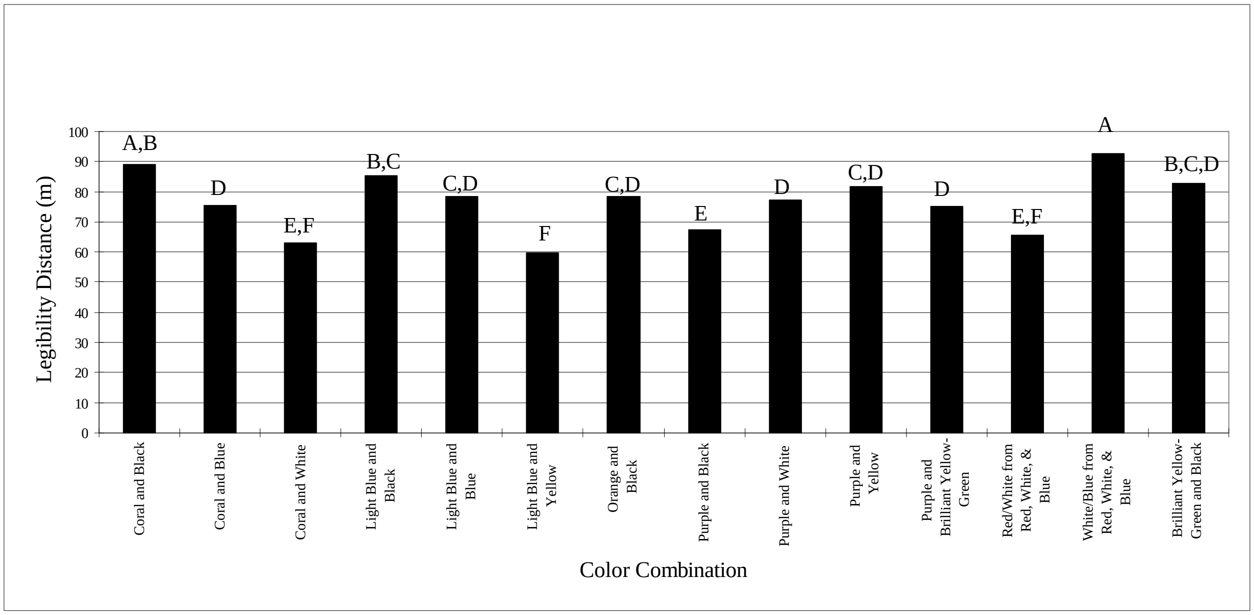
An ANOVA was completed for the test sign designs as a whole (including both text legends and arrow icons) across all other factors or conditions for all participants, with one factor of interest, sign color (SGNCLR) (see Table 3). (Note: Assessment for *sign color based on text legends only* is discussed in the section entitled, "Assessment For Sign Color And Letter Design." Assessment for *sign color based on arrow icons only* is discussed in the section entitled, "Assessment For Sign Color With Arrow Icons Only.") Figure 1 shows the mean legibility distances and SNK groupings for each color combination (see Appendix P for mean legibility values and corresponding standard deviation values). The differences in legibility distances were found to be significant, $F(13,182) = 23.32$, $p = 0.0001$.

Table 3. Analysis of variance table for legibility distance for all sign color combinations for text legends and arrow icons, assessment for all participants.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	13	105787.42	8137.49	23.32	0.0001*
SGNCLR*SNUM	182	63509.02	348.95		
SNUM	14	511241.51	36517.25		
Total	209	680537.95			

*$p < 0.05$

Figure 1 shows that the longest mean legibility distances were obtained for the white on blue portion of the red, white, and blue (92.6 m) and the coral and black (89.1 m) color combinations, both of which were given an SNK grouping of A. The mean legibility distance for the standard orange and black color combinations was 78.6 m, with SNK groupings of C and D.



*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 1. Mean legibility distances (in m) for all sign color combinations for text legends and arrow icons, assessment for all participants.

Assessment For Sign Color With Arrow Icons Only

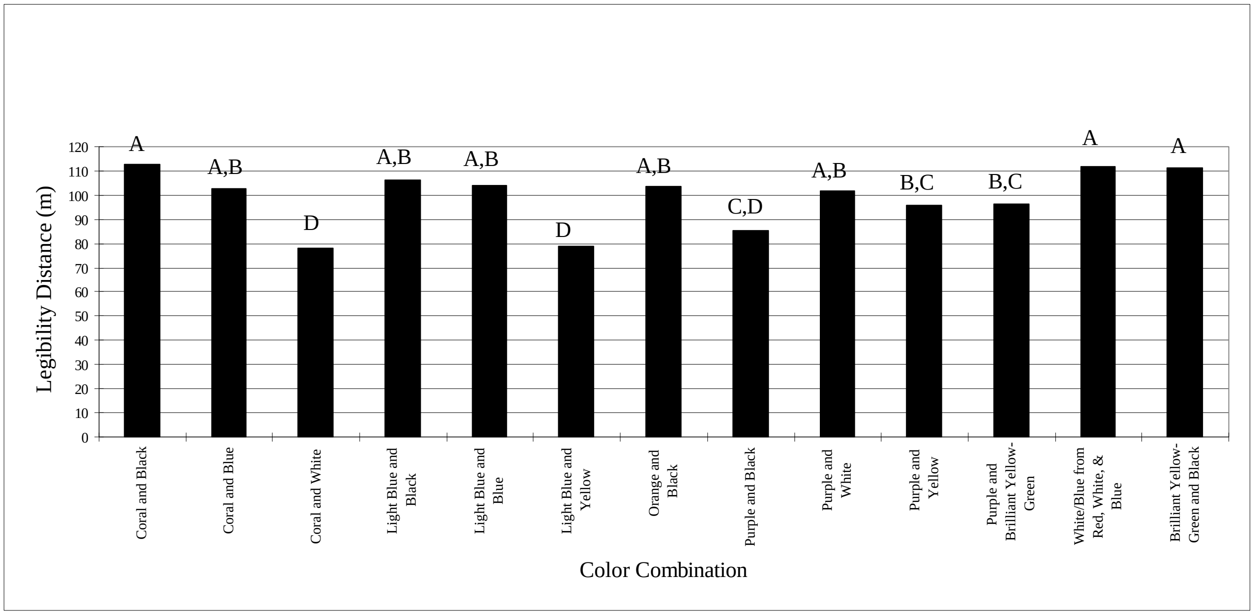
An ANOVA was completed using the legibility data obtained for the arrow icons only across all other factors or conditions for all participants, with one factor of interest, sign color (SGNCLR) (see Table 4). Figure 2 shows the mean legibility distances and SNK groupings for each color combination (see Appendix P for mean legibility values and corresponding standard deviation values). The differences in legibility distances were found to be significant, $F(12,168) = 12.02$, $p = 0.0001$.

Table 4. Analysis of variance table for legibility distance for all sign color combinations for arrow icons only, assessment for all participants.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	12	51897.44	4324.79	12.02	0.0001*
SGNCLR*SNUM	168	60459.11	359.88		
SNUM	14	415098.95	29649.92		
Total	194	527455.5			

*p < 0.05

Figure 2 shows that the longest mean legibility distances were obtained for the coral and black (112.5 m), the white on blue portion of red, white, and blue (111.7 m), brilliant yellow-green and black (111.5 m), light blue and black (106.2 m), light blue and blue (103.8 m), orange and black (103.6 m), coral and blue (102.6 m), and purple and white (101.9 m) color combinations, all of which were given an SNK grouping of A.



*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 2. Mean legibility distances (in m) for all sign color combinations for arrow icons only, assessment for all participants.

Assessment For Sign Color And Letter Design

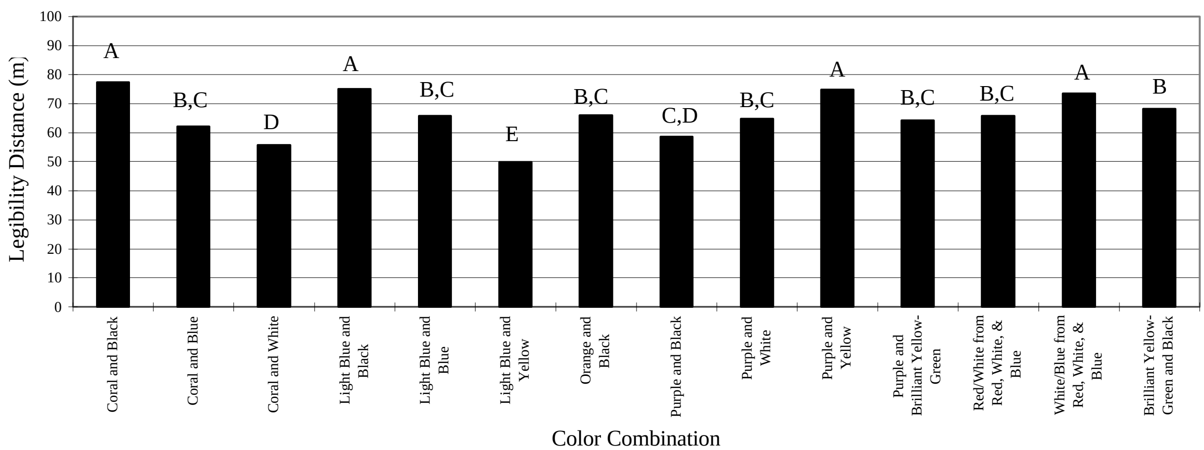
An ANOVA was completed using the legibility data for the text portion of the test signs across all other factors or conditions for all participants, with factors of interest including sign color (SGNCLR), letter height (LTRHGT), and letter series (LTRSER) (see Table 5).

Table 5. Analysis of variance table for legibility distance with factors of interest including sign color, letter height, and letter series, assessment for all participants.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	13	55606.15	4277.40	23.57	0.0001*
SGNCLR*SNUM	182	33031.46	181.49	0.89	0.6900
LTRHGT	1	52088.02	52088.02	163.98	0.0001*
LTRHGT*SNUM	14	4447.06	317.65	1.55	0.1513
LTRSER	1	19919.66	19919.66	76.41	0.0001*
LTRSER*SNUM	14	3649.79	260.70	1.28	0.2778
LTRHGT*LTRSER	1	62.42	62.42	0.61	0.5845
LTRHGT*LTRSER*SNUM	14	1421.16	101.51	0.50	0.9164
LTRSER*SGNCLR	13	15799.69	1215.36	14.69	0.0001*
LTRSER*SGNCLR*SNUM	182	20029.00	110.05	0.54	0.9927
LTRHGT*SGNCLR	11	9010.34	819.12	11.04	0.0001*
LTRHGT*SGNCLR*SNUM	154	8585.07	55.75	0.27	1.0000
LTRHGT*LTRSER*SGNCLR	11	9017.81	819.80	11.03	0.0001*
LTRHGT*LTRSER*SGNCLR*SNUM	154	11449.11	74.34	0.36	1.0000
SNUM	14	217495.38	15535.38	76.05	0.0001
Total	779	461612.12			

*$p < 0.05$

Assessment For Sign Color Based On Text Legends. Figure 3 shows the mean legibility distances by sign color combination for the combined text portions of the test signs (see Appendix P for mean legibility values and corresponding standard deviation values). As shown in Figure 3, the longest mean legibility distances were obtained for the coral and black (77.3 m), the light blue and black (75.1 m), the purple and yellow (74.9 m), and the white on blue portion of the red, white, and blue (73.6 m) color combinations. These color combinations, denoted by the SNK grouping A, produced legibility distances that were not significantly different from each other, but were different from the remaining color combinations. The mean legibility distance for the standard orange and black color combination was 66.1 m, with SNK groupings of B and C. The differences between color combinations across letter heights and letter series (does not include directional arrows) for all participants were found to be significant, F(13.182) = 23.57, p = 0.0001.

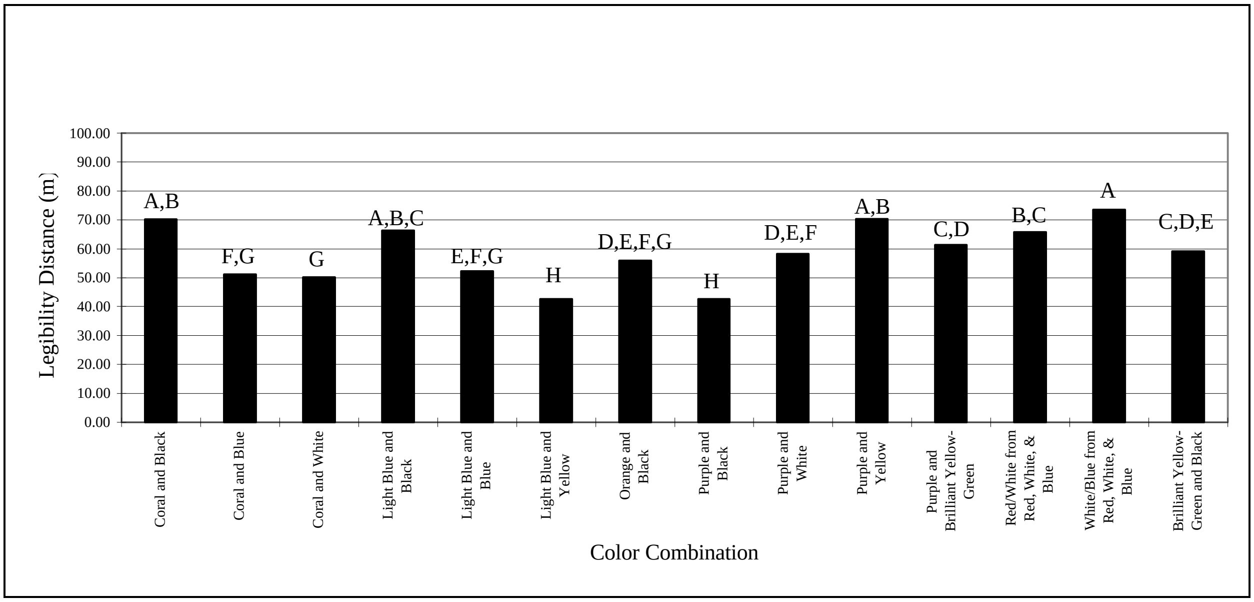


*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 3. Mean legibility distances (in m) for all sign color combinations for text legends only, assessment for all participants.

Assessment For Sign Color By Letter Height. Figures 4 and 5 show the mean legibility distances for the 100-mm and 125-mm letter heights, respectively, for each sign color combination; SNK groupings within letter height are also shown (see Appendix P for mean legibility values and corresponding standard deviation; see Appendix Q for complete ANOVA tables). The interaction of sign color and letter height, F(11,154) = 14.69, p = 0.0001, was found to be significant.

An examination of the effect of sign color on each level of letter height indicated that the longest legibility distances were achieved by different sign colors for each letter height. Figure 4 shows that the longest mean legibility distances for the 100-mm letter height were obtained for the white on blue portion of the red, white, and blue (73.6 m), the purple and yellow (70.3 m), the coral and black (70.2 m), and light blue and black (66.4 m) color combinations, all of which were given an SNK grouping of A. The mean legibility distance for the standard orange and black color combination was 55.9 m, with SNK groupings of D, E, F, and G.

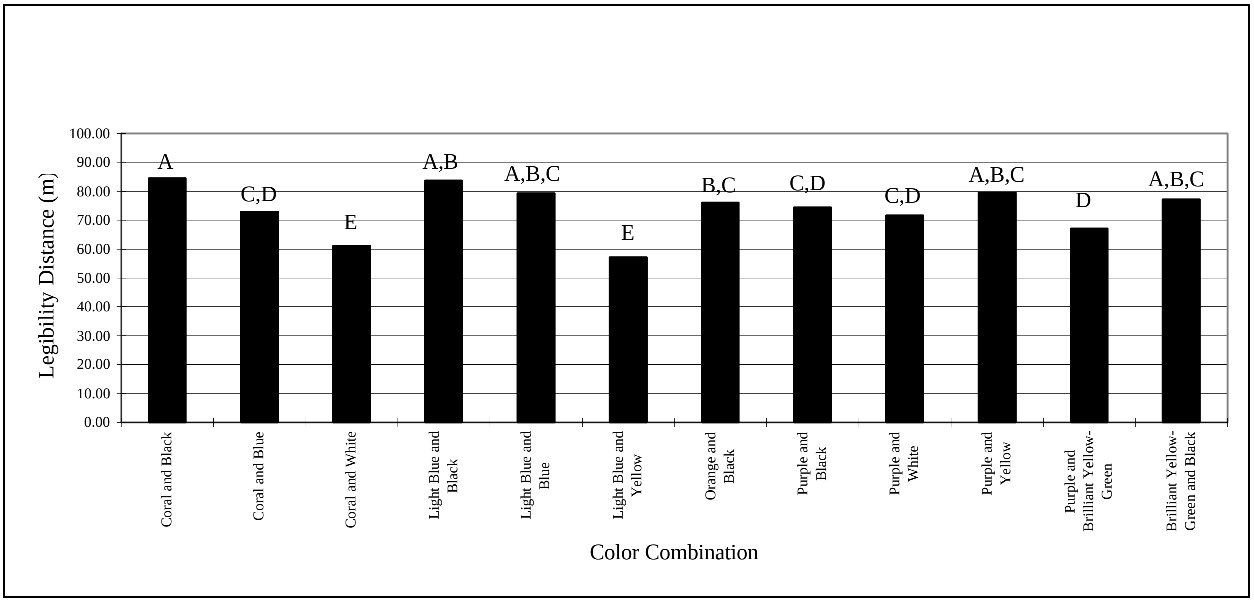


*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 4. Mean legibility distances (in m) for all sign color combinations for text legends with 100-mm letter height only, assessment for all participants.

Figure 5 shows that the longest mean legibility distances for the 125-mm letter height were obtained for the coral and black (84.5 m), light blue and black (83.7 m), purple and yellow (79.6 m), light blue and blue (79.3 m), and brilliant yellow-green and black (77.2 m), all of which were given an SNK grouping of A. The mean legibility distance for the standard orange and black color combination was 76.2 m, with SNK groupings of B and C.

An examination of the individual sign colors (see Table 6 under section entitled, "Assessment For Sign Color, Letter Height, And Letter Series") indicated that letter height was significant for all 12 sign colors tested with the two letter heights. The longest legibility distances (see Figures 4 and 5) were achieved by using the 125-mm letter height for all color combinations. Note that the red, white, and blue color combination was not tested with 125-mm letters.



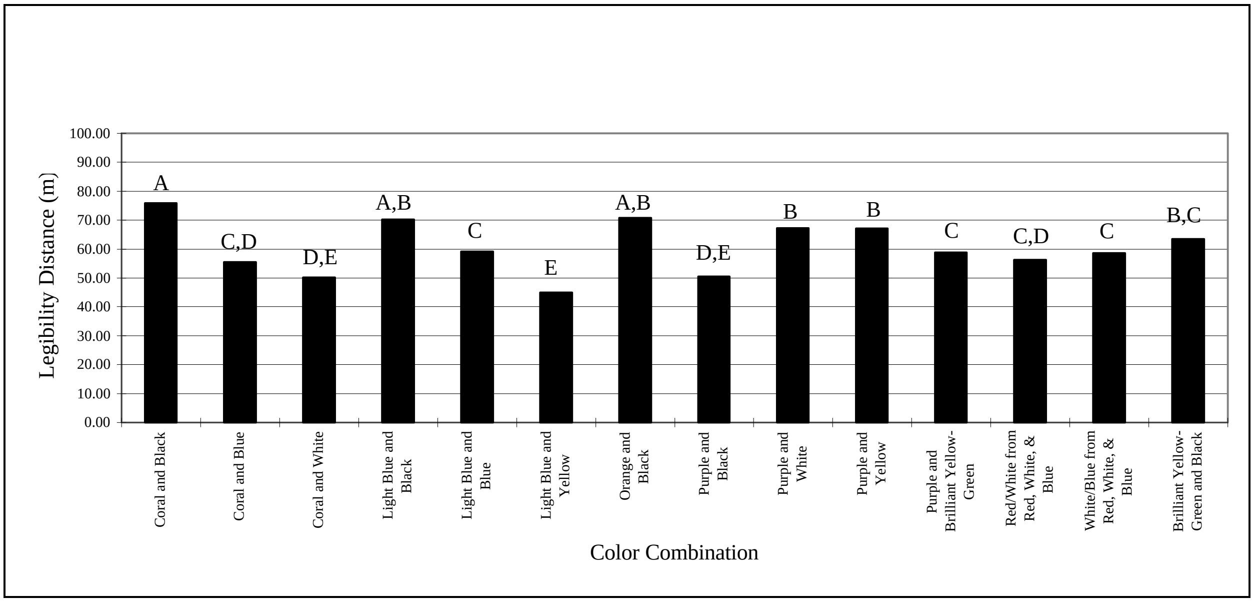
*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 5. Mean legibility distances (in m) for all sign color combinations for text legends with 125-mm letter height only, assessment for all participants.

Assessment For Sign Color And Letter Series. Figures 6 and 7 show the mean legibility distances for the C and D letter series, respectively, for each color combination; SNK groupings within letter series are also shown (see Appendix P for mean legibility values and corresponding standard deviation values; see Appendix Q for complete ANOVA tables). The interaction of sign color and letter series, $F(13,182) = 11.04$, $p = 0.0001$, was found to be significant.

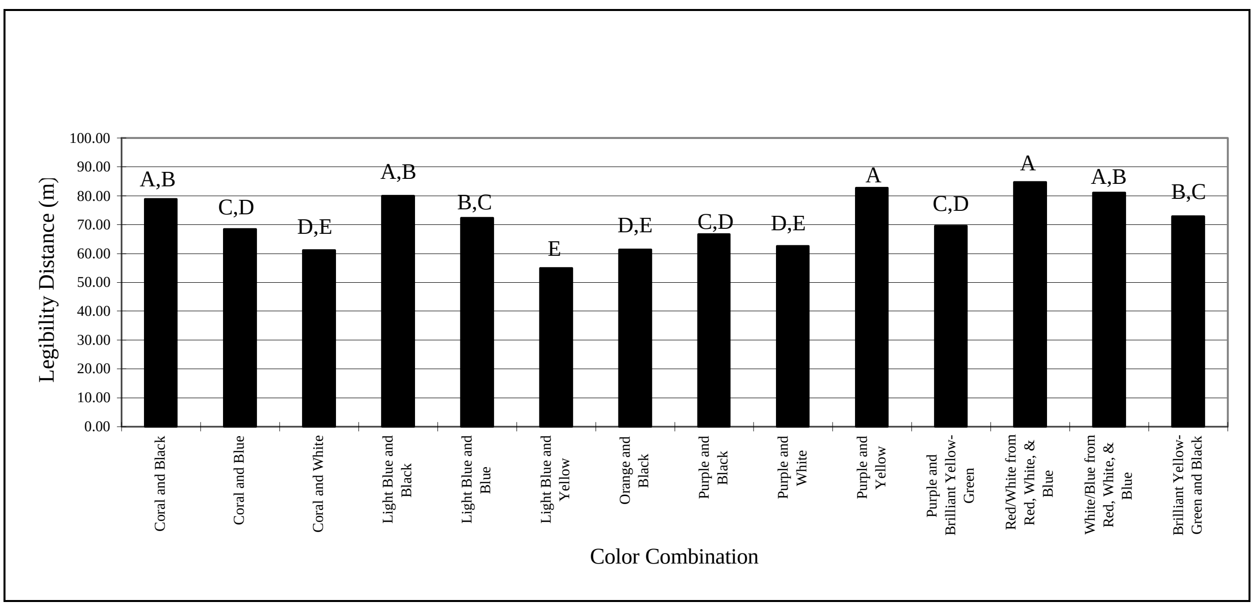
An examination of the effect of sign color on each level of letter series indicates that the longest legibility distances are achieved by different sign colors for each letter height. Figure 6 shows that the longest mean legibility distances for series C text legends were obtained for the coral and black (75.8 m), orange and black (70.8 m), and light blue and black (70.2 m) color combinations, all of which were given an SNK grouping of A.

Figure 7 shows that the longest mean legibility distances for series D text legends were obtained for the red on white portion of the red, white, and blue (84.7 m), purple and yellow (82.7 m), white on blue portion of the red, white, and blue (81.1 m), light blue and black (80.0 m), and coral and black (78.9 m), all of which were given an SNK grouping of A. The mean legibility distance for the standard orange and black color combination was 61.3 m, with SNK groupings of D and E.



*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 6. Mean legibility distances (in m) for all sign color combinations for text legends with Series C letters only, assessment for all participants.



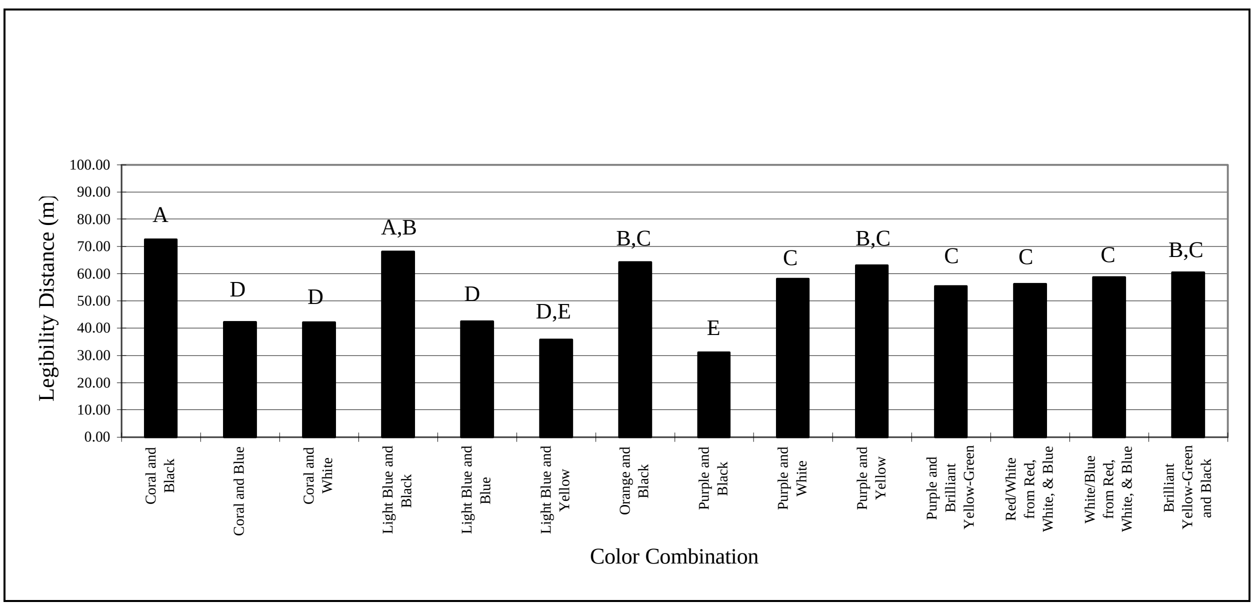
*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 7. Mean legibility distances (in m) for all sign color combinations for text legends with Series D letters only, assessment for all participants.

An examination of the individual sign colors (see Table 6 under section entitled, "Assessment For Sign Color, Letter Height, And Letter Series") indicated that letter series was significant for all sign color combinations tested except the coral and black. The longest legibility distances (see Figures 6 and 7) were achieved by using series D letters for all color combinations except the orange and black and the purple and white color combinations.

Assessment For Sign Color, Letter Height, And Letter Series. While the overall interaction between letter height and letter series was not found to be significant, F(1,14) = 0.61, p = 0.4460, the interaction between sign color, letter height, and letter series was found to be significant, F(11,154) = 11.03, p = 0.0001. Figures 8 through 11 show the mean legibility distances series for each color combination for the four combinations of letter height and letter; SNK groupings within letter series are also shown (see Appendix P for mean legibility values and corresponding standard deviation values; see Appendix Q for complete ANOVA tables). A comparison of the effect of sign color on each combination of letter height and letter series indicated that the longest legibility distances were achieved by different sign colors for each height/series combination.

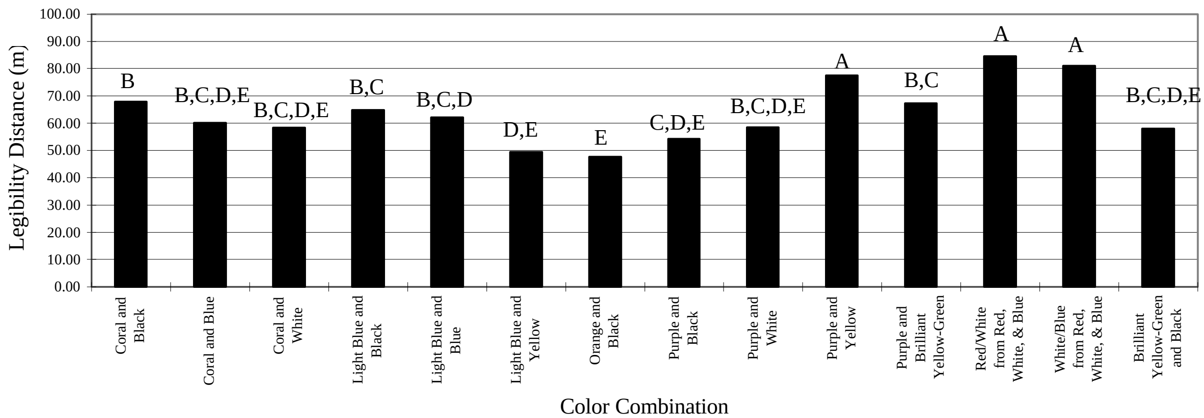
Figure 8 shows that the longest mean legibility distances for 100-mm, series C text legends were obtained for the coral and black (72.6 m) and light blue and black (68.0 m) color combinations, both of which were given an SNK grouping of A. The mean legibility distance for the standard orange and black color combination was 64.2 m, with SNK groupings of B and C.



*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 8. Mean legibility distances (in m) for all sign color combinations for text legends with 100-mm, Series C letters only, assessment for all participants.

Figure 9 shows that the longest mean legibility distances for 100-mm, series D text legends were obtained for the red on white portion of the red, white, and blue (84.7 m), the blue on white portion of the red, white, and blue (81.1 m), and the purple and yellow (77.5 m) color combinations, all of which were given an SNK grouping of A and were significantly different from all other color combinations. The mean legibility distance for the standard orange and black color combination was 47.7 m, with SNK groupings of E, which was also the shortest mean legibility distance.

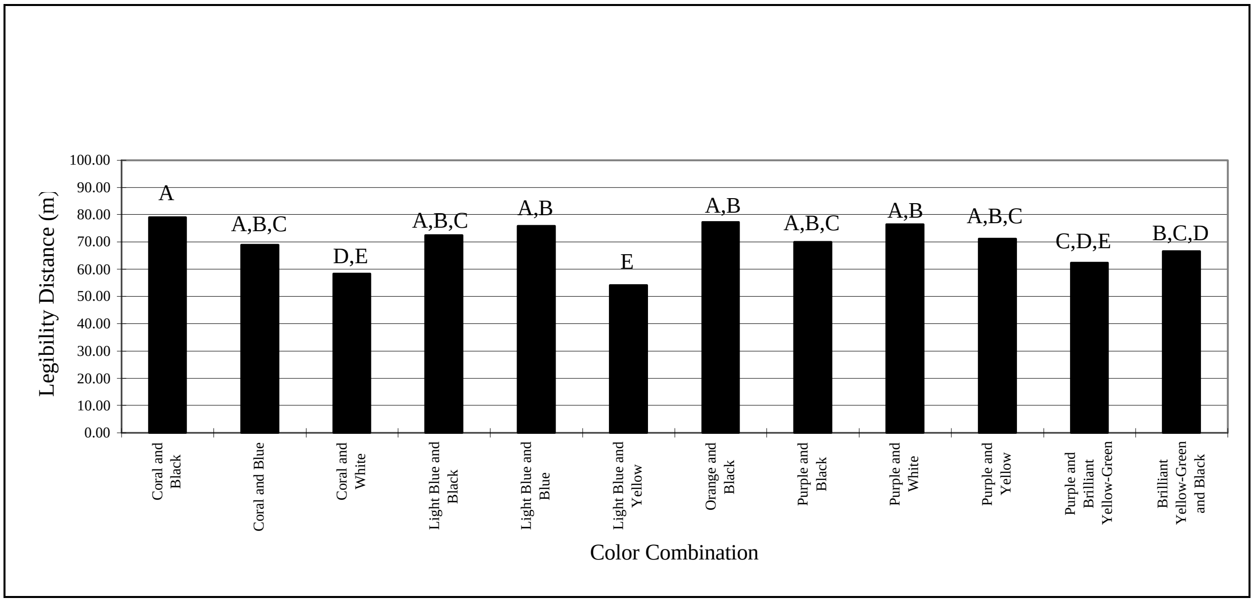


*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 9. Mean legibility distances (in m) for all sign color combinations for text legends with 100-mm, Series D letters only, assessment for all participants.

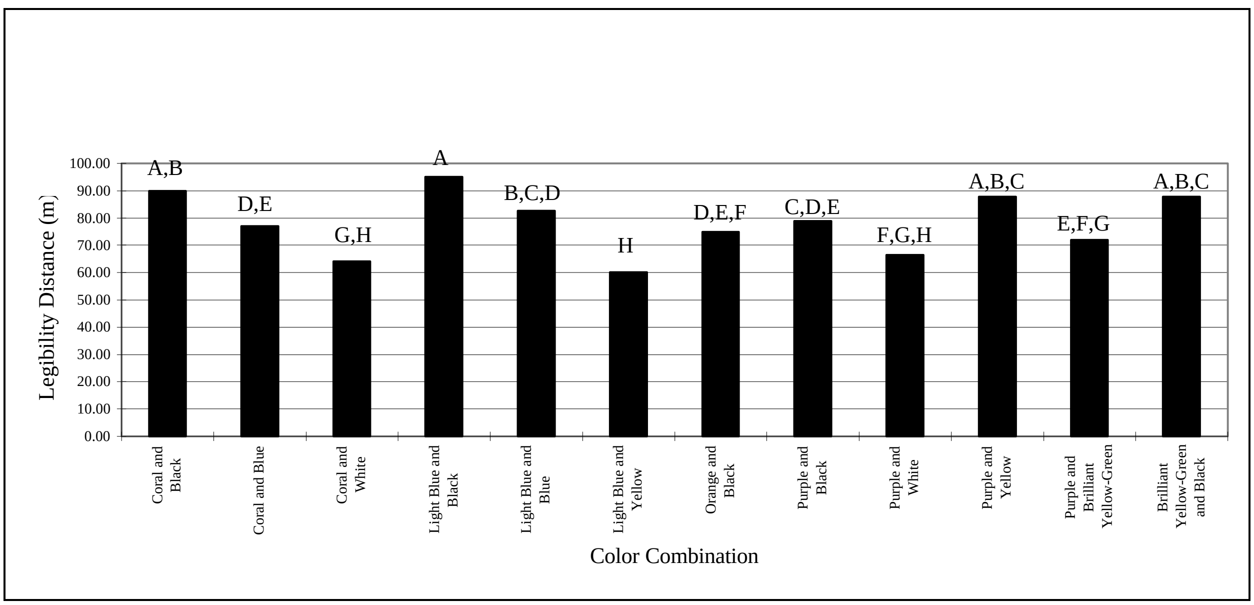
Figure 10 shows that the longest mean legibility distances for 125-mm, series C text legends were obtained for the coral and black (79.1 m), orange and black (77.3 m), purple and white (76.5 m), light blue and blue (75.9 m), light blue and black (72.4 m), purple and yellow (71.2 m), purple and black (70.0 m), and coral and blue (68.9 m) color combinations, all of which were given an SNK grouping of A.

Figure 11 shows that the longest mean legibility distances for 125-mm, series D text legends were obtained for the light blue and black (95.1 m), coral and black (90.0 m), purple and yellow (87.9 m), and brilliant yellow-green and black (87.9 m) color combinations, all of which were given an SNK grouping of A. The mean legibility distance for the standard orange and black color combination was 75.0 m, with SNK groupings of D, E, and F.



*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 10. Mean legibility distances (in m) for all sign color combinations for text legends with 125-mm, Series C letters only, assessment for all participants.



*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 11. Mean legibility distances (in m) for all sign color combinations for text legends with 125-mm, Series D letters only, assessment for all participants.

As discussed in the previous sections, an examination of the individual sign colors (see Table 6) indicated that effects of letter height and letter series were significant for most or all sign color combinations. This examination also revealed that the interaction between letter height and letter series was significant for the following color combinations: (1) coral and black; (2) light blue and black; (3) light blue and blue; (4) orange and black; (5) purple and black; (6) purple and white; and (7) brilliant yellow-green and black (see Figures 6 through 9 for legibility data; see Appendix P for mean legibility values and corresponding standard deviation values; see Appendix Q for complete ANOVA tables by individual sign color combination).

Table 6. P values for individual sign color combination, assessment for letter height and letter series.

EFFECT	Color Combination†													
	C & BLK	**C & BLU**	**C & WH**	**LBLU & BLK**	**LBLU & BLU**	**LBLU & Y**	**O & BLK**	**P & BLK**	**P & WH**	**P & Y**	**P & YG**	**R/WH R,WH & BLU**	**WH/ BLU R, WH& BLU**	**YG & BLK**
LTRHGT	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0022	0.0055	-	-	0.0001
LTRSER	0.2063	0.0001	0.0024	0.0004	0.0001	0.0361	0.0115	0.0001	0.0291	0.0001	0.0002	0.0001	0.0001	0.0004
LTRHGT* LTRSER	0.0017	0.0552	0.0609	0.0001	0.0036	0.2026	0.0041	0.0162	0.0467	0.6336	0.4906	-	-	0.0001

†Color key: BLK = Black, C = Coral, BLU = Blue, LBLU = Light Blue, O = Orange, P = Purple, R = Red, Y = Yellow, YG = Brilliant Yellow-Green, WH = White

Assessment For Letter Height And Letter Series Main Effects. The mean legibility distance for the 125-mm letter height (73.7 m) was longer than the mean legibility distance for the 100-mm letter height (59.3 m) across all color combinations and letter series for all participants. This difference between letter heights was found to be significant, $F(1,14) = 163.98$, $p = 0.0001$.

The mean legibility distance for the D series letters (70.7 m) was longer than the mean legibility distance for the C series letters (60.7 m) across all color combinations and letter heights for all participants. This difference between letter series was found to be significant, $F(1,14) = 76.41$, $p = 0.0001$.

Assessment For Visibility Classification

An ANOVA was completed for the test sign designs as a whole (including both text legends and arrow icons) with factors of interest including visibility condition (VISCON) and sign color (SGNCLR) (see Table 7).

Table 7. Analysis of variance table for legibility distance for all sign color combinations with full text legends and arrow icons, assessment for all participants based on visibility condition.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
VISCON	1	42876.60	42876.60	1.19	0.2951
SNUM(VISCON)	13	468364.90	36028.07		
SGNCLR	13	107764.67	8289.59	26.37	0.0001*
VISCON*SGNCLR	13	10377.21	798.25	2.54	0.0032*
SGNCLR*SNUM(VISCON)	169	53131.81	314.39		
Total	209	682515.19			

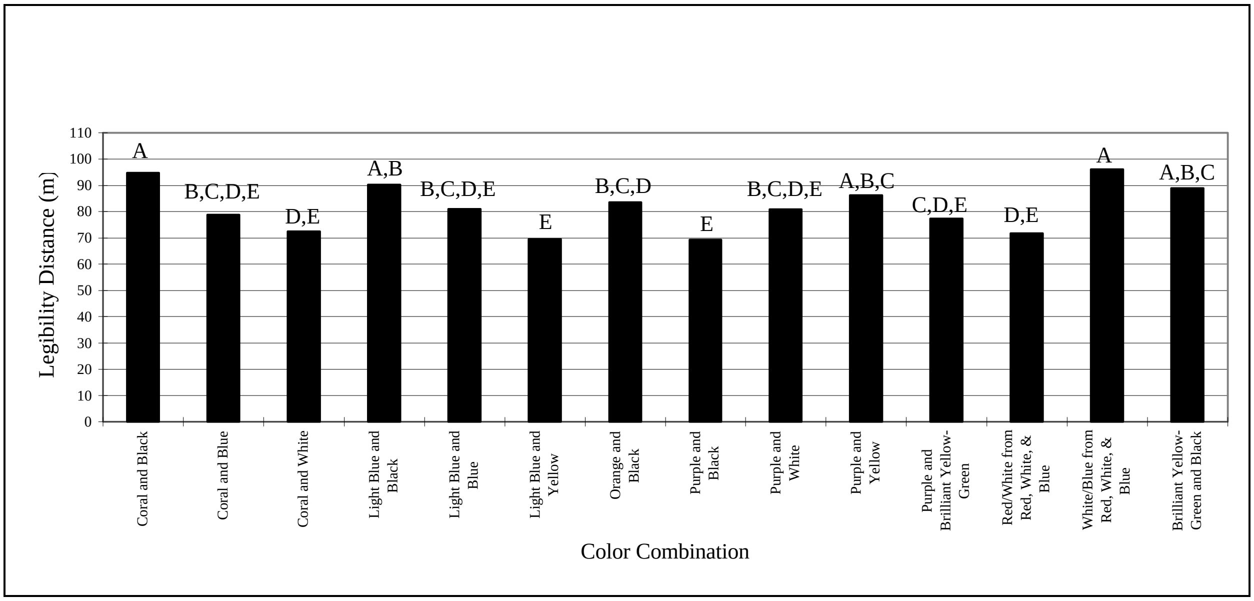
*p < 0.05

While the mean legibility distance under day viewing conditions (mean = 81.9 m, STD = 36.03) was longer than the mean legibility distance under night viewing conditions (mean = 69.7 m, STD = 27.97) across all color combinations and for all text and arrow legends for all participants, this difference was not found to be statistically significant, $F(1,13) = 1.19$, $p = 0.2951$.

Sign color, $F(13,169) = 26.37$, $p = 0.0001$, was found to be significant for all participants regardless of visibility condition. See section entitled, “Assessment For Sign Color” for further discussion.

The interaction of sign color and visibility condition was found to be significant, $F(13,169) = 2.54$, $p = 0.0032$. A comparison of the effect of sign color on each level of visibility, day and night (see Figures 10 and 11), indicates that the longest legibility distances are achieved by different sign colors for each visibility condition (see Appendix Q for complete ANOVA tables).

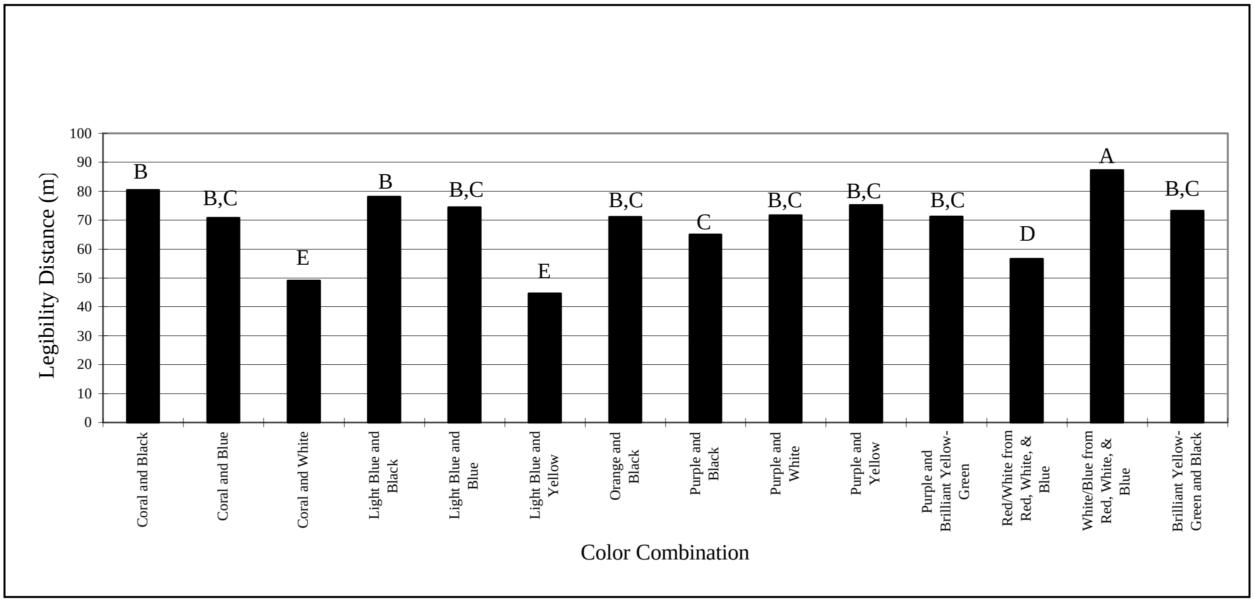
Figure 12 shows that the longest mean legibility distances under daytime viewing conditions were obtained for the white on blue portion of the red, white, and blue (96.1 m), coral and black (94.8 m), light blue and black (90.3 m), brilliant yellow-green and black (89.0 m), and purple and yellow (86.2 m) color combinations, all of which were given an SNK grouping of A. The mean legibility distance for the standard orange and black color combination was 83.6 m, with SNK groupings B, C, and D. (See Appendix P for mean legibility values and corresponding standard deviation values.)



*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 12. Mean legibility distances (in m) under day viewing conditions for all sign color combinations with full text legends and arrow icons, assessment for all participants.

Figure 13 shows that the longest mean legibility distance under nighttime viewing conditions was obtained for the white on blue portion of the red, white, and blue color combination (87.4 m), with SNK grouping A. This was followed by coral and black (80.5 m) and light blue and black (78.2 m), and seven other color combinations with SNK grouping B. The mean legibility distance for the standard orange and black color combination was 71.0 m, with B and C SNK groupings. (See Appendix P for mean legibility values and corresponding standard deviation values.)



*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 13. Mean legibility distances (in m) under night viewing conditions for all sign color combinations with full text legends and arrow icons, assessment for all participants.

Assessment For Participant Age Classification

An ANOVA was completed for the test signs as a whole (including both text legends and arrow icons), with factors of interest including age (AGE) and sign color (SGNCLR) (see Table 8).

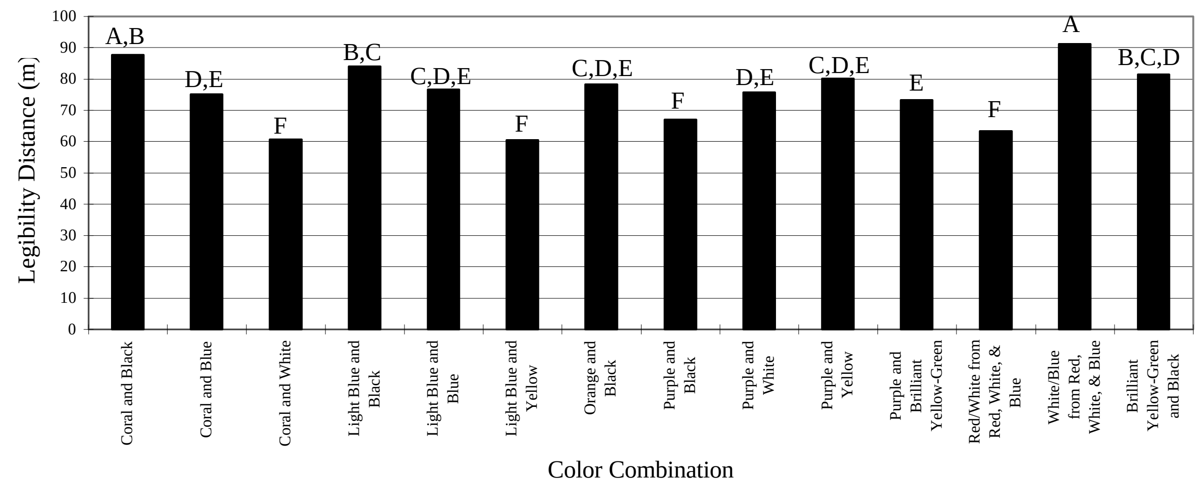
Table 8. Analysis of variance table for legibility distance for all sign color combinations with full text legends and arrow icons, assessment for participants based on age (does not include data for 42-year-old male with known color vision deficiency).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	1	306036.12	306036.17	20.47	0.0007*
SNUM(AGE)	12	179440.81	14953.40		
SGNCLR	13	93721.78	7209.37	24.94	0.0001*
AGE*SGNCLR	13	5994.97	461.15	1.60	0.0916
SGNCLR*SNUM(AGE)	156	45093.76	289.06		
Total	195	630287.44			

*p < 0.05

The mean legibility distance for younger participants (mean = 90.4 m, STD = 32.32) was longer than the mean legibility distance for older participants (mean = 56.3 m, STD = 23.37) across all color combinations and for all text and arrow legends. This difference was found to be significant, $F(1,12) = 20.47$, $p = 0.0007$.

Sign color, $F(13,156) = 24.94$, $p = 0.0001$, was found to be significant for all younger and older participants. Figure 14 shows that the longest mean legibility distance for all younger and older participants, excluding the 42-year-old with known color vision deficiency, was obtained for the white on blue portion of the red, white, and blue (91.1 m) and coral and black (87.8 m) color combinations, both of which were given SNK grouping A. The mean legibility distance for the standard orange and black color combination was 78.2 m, with SNK groupings of C, D, and E. (See Appendix P for mean legibility values and corresponding standard deviation values.)



*Student-Newman-Keuls (SNK) multiple range test used to test main effects; means with the same SNK letter grouping are not significantly different.

Figure 14. Mean legibility distances (in m) for younger and older participants (except 42 year old male) for all sign color combinations (with text legends and arrow icons).

While there were significant differences due to age and sign color independently of each other, the interaction between sign color and age was not found to be significant.

Subjective Preference Data

The participants were asked to rate each test sign relative to readability. The 5-point scale ranged from not readable (value = 1) to extremely readable (value = 5). The data were analyzed in terms of sign color preference overall and as a function of visibility condition, participant age, and color vision deficiency.

Assessment For Overall Participant Preference

An ANOVA was completed for the sign color ratings, with one factor of interest, sign color (SGNCLR) (see Table 9). Table 10 presents the mean response value and standard deviation for each sign color combination and the corresponding SNK groupings. The highest mean preference rating was given to the standard orange and black color combination, with an overall mean rating of 3.9000 and SNK grouping A. As shown in Table 10, only three other color combinations were also given the SNK A grouping, including the coral and black, the light blue and black, and the purple and white color combinations. The similar A grouping indicates that the subjective ratings for these sign color combinations were not found to be significantly different from one another; however, sign color was found to be a significant effect overall, $F(12,168) = 20.23$, $p = 0.0001$.

Table 9. Analysis of variance table for overall assessment of subjective ratings of readability for all sign color combinations.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	12	132.61	11.05	20.23	0.0001*
SGNCLR*SNUM	168	91.79	0.55		
SNUM	14	46.05	3.29		
Total	194	270.45			

*p < 0.05

Assessment For Participant Preference And Visibility Condition

An ANOVA was completed for the sign color ratings, with two factors of interest, visibility condition (VISCON) and sign color (SGNCLR) (see Table 11).

While the mean preference rating for daytime participants (mean = 3.0823, STD = 0.8846) was greater than the mean preference rating for nighttime participants (mean = 3.0525, STD = 1.0283) across all color combinations, there was no significant difference between the two groups, $F(1,13) = 0.06$, $p = 0.8100$.

The effect due to sign color was found to be significant for all younger and older participants, $F(12,144) = 19.31$, $p = 0.0001$. Refer to section entitled, “Assessment For Overall Participant Preference.”

Table 10. Mean response values (in descending order) to five-point Likert-type question rating overall readability for all sign color combinations.

Sign Color Combination*	Mean Rating**	STD	SNK Grouping
Orange and Black	3.9000	0.7120	A
Coral and Black	3.7167	0.7391	A,B
Light Blue and Black	3.5667	0.6789	A,B,C
Purple and White	3.4333	0.5683	A,B,C
Purple and Yellow	3.3667	0.7649	B,C
Brilliant Yellow-Green and Black	3.2667	0.9072	B,C
Light Blue and Blue	3.2500	0.7514	B,C
Coral and Blue	3.1667	0.6989	B,C
Purple and Brilliant Yellow-Green	3.1667	0.9129	B,C
Red, White, and Blue	3.1000	0.8298	C
Purple and Black	2.4833	0.6757	D
Coral and White	2.1667	0.8339	D,E
Light Blue and Yellow	1.8000	0.7144	E

* Data for sets of test signs with the same color combination were combined to obtain overall ratings for each color combination.
** The scale ranged from Not Readable (Rating = 1) to Extremely Readable (Rating = 5).

Table 11. Analysis of variance table for ratings of readability for all sign color combinations, assessment for participants based on visibility condition.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
VISCON	1	0.21	0.21	0.06	0.8100
SNUM(VISCON)	13	45.84	3.53		
SGNCLR	12	137.64	11.47	23.38	0.0001*
VISCON*SGNCLR	12	15.26	1.27	2.59	0.0036*
SGNCLR*SNUM(VISCON)	156	76.54	0.49		
Total	194	275.49			

*$p < 0.05$

The interaction between sign color and visibility condition was found to be significant, $F(12,156) = 2.59$, $p = 0.0036$. Tables 12 and 13 present the mean response value and standard deviation for each sign color combination and the corresponding SNK groupings for the daytime and nighttime visibility conditions respectively (see Appendix Q for complete ANOVA tables). A comparison of the effect of sign color on each level of visibility, day and night, indicates that the highest preference ratings are given to different signs colors for each visibility condition. For the daytime viewing condition, the highest mean preference rating was given to the standard orange and black color combination, with an overall mean rating of 3.8889 and SNK grouping A. As shown in Table 12, six other color combinations were also given the SNK A grouping, including the coral and black, the light blue and black, the coral and blue, the purple and white, the purple and yellow, and the brilliant yellow-green and black color combinations. For the nighttime viewing condition, the highest mean preference rating was given to the standard orange and black color combination, with an overall mean rating of 3.9167 and SNK grouping A. As shown in Table 13, eight other color combinations were also given the SNK A grouping, including the coral and black, the purple and yellow, the light blue and black, the purple and white, the purple and yellow-green, the light blue and blue, the red, white and blue, and the brilliant yellow-green and black color combinations.

Table 12. Mean response values (in descending order) to five-point Likert-type question rating readability of the test signs, assessment for daytime participants.

Sign Color Combination*	Mean Rating**	STD	SNK Grouping
Orange and Black	3.8889	0.7584	A
Coral and Black	3.6944	0.7503	A,B
Light Blue and Black	3.5556	0.7048	A,B,C
Coral and Blue	3.3333	0.6860	A,B,C
Purple and White	3.3333	0.4851	A,B,C
Purple and Yellow	3.2222	0.6468	A,B,C
Brilliant Yellow-Green and Black	3.2222	1.0033	A,B,C
Light Blue and Blue	3.1111	0.5830	B,C,D
Red, White, and Blue	2.9444	0.8243	D,C
Purple and Brilliant Yellow-Green	2.8889	0.9003	D,C
Coral and White	2.5000	0.7859	D,E
Purple and Black	2.4444	0.6157	D,E
Light Blue and Yellow	2.0000	0.7670	E

* Data for sets of test signs with the same color combination were combined to obtain overall ratings for each color combination.
** The scale ranged from Not Readable (Rating = 1) to Extremely Readable (Rating = 5).

Assessment For Participant Preference And Age

An ANOVA was completed for the sign color ratings, with two factors of interest, sign color (SGNCLR) and age (AGE) (see Table 14).

While the mean preference rating for younger participants (mean = 3.1412, STD = 0.9461) was greater than the mean preference rating for older participants (mean = 3.0525, STD = 0.9758) across all color combinations, there was no significant difference between the two groups, $F(1,12) = 0.25$, $p = 0.6245$.

Table 13. Mean response values (in descending order) to five-point Likert-type question rating readability of the test signs, assessment for nighttime participants.

Sign Color Combination*	Mean Rating**	STD	SNK Grouping
Orange and Black	3.9167	0.6686	A
Coral and Black	3.7500	0.7538	A,B
Purple and Yellow	3.5833	0.9003	A,B
Light Blue and Black	3.5833	0.6686	A,B
Purple and White	3.5833	0.6686	A,B
Purple and Brilliant Yellow-Green	3.5833	0.7930	A,B
Light Blue and Blue	3.4583	0.9405	A,B
Red, White, and Blue	3.3333	0.8044	A,B
Brilliant Yellow-Green and Black	3.3333	0.7785	A,B
Coral and Blue	2.9167	0.6686	B,C
Purple and Black	2.5417	0.7821	C
Coral and White	1.6667	0.6513	D
Light Blue and Yellow	1.5000	0.5222	D

* Data for sets of test signs with the same color combination were combined to obtain overall ratings for each color combination.
** The scale ranged from Not Readable (Rating = 1) to Extremely Readable (Rating = 5).

Table 14. Analysis of variance table for ratings of readability for all sign color combinations, assessment for participants based on age (except for 42-year-old male).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	1	0.95	0.95	0.25	0.6245
SNUM(AGE)	12	45.04	3.75		
SGNCLR	12	129.43	10.79	19.31	0.0001*
AGE*SGNCLR	12	5.30	0.44	0.79	0.6586
SGNCLR*SNUM(AGE)	144	80.42	0.56		
Total	181	261.14			

*$p < 0.05$

The effect due to sign color was found to be significant for all younger and older participants, $F(12,144) = 19.31$, $p = 0.0001$. Table 15 presents the mean response value and standard deviation for each sign color combination and the corresponding SNK groupings. The highest mean preference rating was given to the standard orange and black color combination, with an overall mean rating of 3.8929 and SNK grouping A. As shown in Table 15, four other color combinations were also given the SNK A grouping, including the coral and black, the light blue and black, the purple and white, and the purple and yellow color combinations.

The interaction between sign color and age was not found to be significant.

Table 15. Mean response values (in descending order) to five-point Likert-type question rating readability of the test signs, assessment for participants based on age (except 42-year-old male).

Sign Color Combination*	Mean Rating**	STD	SNK Grouping
Orange and Black	3.8929	0.6853	A
Coral and Black	3.7679	0.7389	A,B
Light Blue and Black	3.5357	0.6929	A,B,C
Purple and White	3.4286	0.5727	A,B,C
Purple and Yellow	3.3929	0.7860	A,B,C
Light Blue and Blue	3.2679	0.7756	B,C
Brilliant Yellow-Green and Black	3.2500	0.9280	B,C
Coral and Blue	3.1786	0.7228	B,C
Purple and Brilliant Yellow-Green	3.1786	0.9449	B,C
Red, White, and Blue	3.1071	0.8303	C
Purple and Black	2.4821	0.6869	D
Coral and White	2.0714	0.7664	E
Light Blue and Yellow	1.7857	0.7382	E

* Data for sets of test signs with the same color combination were combined to obtain overall ratings for each color combination.
** The scale ranged from Not Readable (Rating = 1) to Extremely Readable (Rating = 5).

DISCUSSION

The discussion that follows is presented in terms of the legibility evaluation of four currently unassigned background traffic sign colors, sign legend colors, and other design parameters, for the purpose of determining which combinations would produce the best legibility distances under day and night conditions for both older and younger participants. A summary of those sign color combinations found to produce statistically greater legibility distances in the various data subset analyses and of those combinations found to produce statistically greater participant preference ratings is presented in Table 16.

This section presents a brief discussion of the legibility performance of the test signs relative to assessments of the data subset analyses described in Table 16, specifically sign color, letter design, visibility condition, and participant age. A brief discussion of the external validity of these results is also presented.

Table 16. Summary of sign color combinations producing statistically greater legibility results in the various data subset analyses and those combinations producing statistically greater participant preference ratings.

	Sign Color Combinations†													
Data Subsets	**C & BLK**	**C & BLU**	**C & WH**	**LBLU & BLK**	**LBLU & BLU**	**LBLU & Y**	**O & BLK**	**P & BLK**	**P & WH**	**P & Y**	**P & YG**	**R/WH R,WH & BLU**	**WH/ BLU R, WH& BLU**	**YG & BLK**
For All Participants and Day/Night Conditions														
Overall	✓												✓	
Arrows	✓	✓		✓	✓		✓		✓				✓	✓
Text	✓			✓						✓			✓	
By Letter Height														
100 mm	✓			✓						✓			✓	
125 mm	✓			✓	✓					✓				✓
By Letter Series														
C Series	✓			✓			✓							
D Series	✓			✓						✓		✓	✓	
By Letter Height (100/125) and Letter Series (C or D)														
100 / C	✓			✓										
100 / D										✓		✓	✓	
125 / C	✓	✓		✓	✓		✓	✓	✓	✓				
125 / D	✓			✓						✓				✓
By Visibility Condition														
Day	✓			✓						✓			✓	✓
Night													✓	

†Color key: BLK = Black, C = Coral, BLU = Blue, LBLU = Light Blue, O = Orange, P = Purple, R = Red, Y = Yellow, YG = Brilliant Yellow-Green, WH = White

Table 16. (Continued).

	SIGN COLOR COMBINATIONS													
Data Subsets	**C & BLK**	**C & BLU**	**C & WH**	**LBLU & BLK**	**LBLU & BLU**	**LBLU & Y**	**O & BLK**	**P & BLK**	**P & WH**	**P & Y**	**P & YG**	**R/WH R,WH & BLU**	**WH/ BLU R, WH& BLU**	**YG & BLK**
***Subject Preference Rating*‡**														
Overall*	✓			✓			✓		✓	✓				
Day	✓	✓		✓			✓		✓	✓				✓
Night	✓			✓	✓		✓		✓	✓	✓		✓	✓
By Participant Age‡														

†Color key: BLK = Black, C = Coral, BLU = Blue, LBLU = Light Blue, O = Orange, P = Purple, R = Red, Y = Yellow, YG = Brilliant Yellow-Green, WH = White

‡Analysis based on age classification did not yield statistically significant results, thus best sign color results are not indicated in this table.

*Refer to sections entitled, “Assessment For Overall Participant Preference,” and “Assessment For Participant Preference And Age,” for further information.

Sign Color

General Comments

The present data indicate that the sign color combinations that yielded the best legibility results vary depending on the type of legend used. An examination of the signs overall indicated that the best legibility results were obtained with the white on blue portion of the red, white, and blue color combination and the coral and black color combination. Examination of text legends only, however, revealed that the best legibility results were obtained with the coral and black, the light blue and black, the purple and yellow, and the white on blue portion of the red, white, and blue color combinations. Examination of arrow icons only showed an even larger array of color combinations yielding long legibility distances, including coral and black, the white on blue portion of red, white, and blue, brilliant yellow-green and black, light blue and black, light blue and blue, orange and black, coral and blue, and purple and white.

A proper assessment of sign legibility depends on the type of message to be conveyed by the sign. In the present case, information incorporating a directional arrow requires consideration of text and arrow icons together rather than text or arrow legends alone. Note that the coral and black, the light blue and black, and the white on blue portion of the red, white, and blue color combinations performed consistently well for both text and arrow legends, as well as overall. The purple and yellow color combination, which provided average overall results, performed consistently well for text legends. The orange and black color combination, which performed well for the arrow legend, yielded average legibility distances overall and for the text legends alone.

Comments Regarding Individual Sign Color Combinations

The present study determined that several color combinations composed of the currently unassigned highway traffic sign colors, including coral, light blue, and purple, produced longer legibility distances, under day and night conditions for younger and older participants, than standard orange and black traffic signs. The study also determined that several of the specified color combinations produced much shorter legibility distances, which suggests that those color combinations were not as useful in conveying information quickly and clearly under the test conditions. This section provides a brief discussion of the legibility results and subjective comments for each color combination tested in Study 1.

Coral with Black Legend. The coral and black color combination produced long legibility distances for both letter heights and the directional arrow under day and night conditions for all participant groups. Note that while this combination received a high preference rating (moderately to very easy to read), two participants stated that they did not like this color combination. In addition, when asked what color was shown on the sign (and not given any color choices from which to choose), two participants stated that the background color was orange. Several participants also mentioned that the top legend featured too many letters spaced too closely together, which made the legend difficult to read. Overall, however, this color combination was rated highly, with several participants stating that this was a "good" color combination with letters that were easy to pick out.

Coral with Blue Legend. The coral and blue color combination produced middle-range legibility distances for both letter heights and the directional arrow under day and night conditions for all participant groups. One night participant reported that the coral and blue test signs did not feature enough contrast, which may explain why this color combination did not perform as well as the coral and black color combination. Another older night participant, S12, was unable to read the top legend on one of the coral and blue test signs. As a result of these types of problems, this color combination received an average overall preference rating (moderately to somewhat readable); however, reactions from the participants were mixed. Most participants who stated an opinion did not like this color combination, and one participant stated that there was not enough contrast in the sign, making it more difficult to read. On the other hand, two participants thought the signs featured good contrast, although participants also noted that letter spacing made reading the signs difficult.

Coral with White Legend. The coral and white color combination produced consistently shorter legibility distances for both letter heights and the directional arrow under day and night conditions for all participants. In fact, two older night participants (S11 and S12, both with normal color vision) experienced great difficulty reading these signs. Neither participant was able to read the top legend on the sign with series C letters, and participant S11 was unable to read the bottom legend on that same sign. In addition, participant S12 was not able to read the test sign with series D letters, and participant S11 was unable to read the top legend on that sign. This color combination received the second lowest overall rating (somewhat to moderately readable), and nothing but negative comments about readability. Most participants felt that the signs did not feature enough contrast, were difficult to read, and were too light overall. In addition, most participants did not like this color combination.

Light Blue with Black Legend. The light blue and black color combination produced long legibility distances for both letter heights and the directional arrow under both day and night conditions for all participants. This combination received a middle to high preference rating (moderately to very readable), and most participants with an opinion liked this color combination. Two participants, however, did not like this color combination, and two participants mentioned that the top legend featured too many letters too close together, which made the legend difficult to read.

Light Blue with Blue Legend. The light blue and blue color combination produced shorter legibility distances for the smaller letter height, but produced comparatively longer legibility distances for the larger letter height and the directional arrow. In fact, two older participants (S11 and S12) were unable to read the top legend on the sign with series C letters. Previous research (Allen and Straub, 1955) has shown that irradiation causes dark letters to appear smaller, and it is most likely the irradiation effect that has caused the smaller letter height to be more difficult to read in this case. It is hypothesized that the larger letters used in the bottom sign legends counteracted this effect and thus improved the legibility of the sign legend, a phenomenon that has been supported by previous research in this area (e.g., Forbes and Holmes, 1939). The difficulties with this color caused the participants to give it an average preference rating (moderately to very readable), and participant reactions were mixed. Three participants did not like this color combination, and one participant found that the signs were not easy to read. Four of the participants who stated an opinion, however, thought that these signs featured good contrast and that this color combination was "good."

Light Blue with Yellow Legend. The light blue and yellow color combination produced some of the shortest legibility distances for both letter heights and the directional arrow under day and night conditions for all participants. Almost all of the participants found this color combination particularly difficult to read, and often complained that the sign was too light and featured low contrast, which complicated reading. Several participants also mentioned that the letters tended to "vibrate" or "blend together," a probable result of irradiation effects. One older participant, S12, was unable to read the legends composed of either series C or D letters in the smaller letter height. As a result of the many difficulties experienced by participants in attempting to read these signs, this color combination received the lowest overall preference rating (not readable to somewhat readable), and several participants stated that this was a "poor" color combination for traffic signs.

Orange with Black Legend. The standard orange and black color combination produced legibility distances in the middle range of the distances observed in the present study for both letter heights and the directional arrow under day and night conditions for all participant groups. While the observed distances were not outstanding, participants still thought highly of this color combination. Most of the participants who expressed an opinion stated that this was a "good color combination," that this color combination produced better contrast between the sign and background, thereby improving visibility from a distance, and that the letters were easier to pick out. One color vision-deficient participant (S13), however, stated that this was "not a good combination." Another participant mentioned that the top legend was made up of too many letters, which made reading the legend difficult, a fact that may be supported by the inability of older participant S12 to read the top legend composed of series C letters on one of the test signs. Although the legibility distances were not the longest and despite the problems mentioned above, this color combination received the highest subjective preference rating (moderately to very readable), which seems to indicate that participants preferred this combination for use on traffic signs.

Purple with Black Legend. The purple and black color combination produced legibility distances in the low to middle range of distances observed in the present study for both letter heights and the directional arrow under day and night conditions for all participant groups. In fact, three older participants, S10, S11, and S12, were not able to read the 100-mm legend composed of series C letters. While one participant stated that purple and black yielded “good” contrast and a “good” color combination, none of the other comments were positive. Other comments included the following: not enough contrast, “bad” color combination, difficult to read, and colors were “too dark.” One participant also noted that the Velcro used to mount left and right arrow plaques interfered with one’s ability to read the up arrow mounted directly on the sign face, the shape of which became distorted due to the presence of other dark objects nearby on the sign face. The poor legibility distances and problems noted above resulted in one of the lowest overall preference ratings (somewhat to moderately readable).

Purple with White Legend. The purple and white color combination produced legibility distances in the middle range of distances observed in the present study for both letter heights under day and night conditions for all participant groups. While the observed distances were not outstanding, participants still thought highly of this color combination. Most of the participants who expressed an opinion stated that this was a “good color combination,” that this color combination produced “good” contrast, and that the signs were “very clear.” Other participants disliked this color combination, thought the signs did not feature enough contrast for readability, and complained that the letters “bled or blurred together...with longer words.” This color combination received a higher overall subjective preference rating (moderately to very readable).

Purple with Yellow Legend. The purple and yellow color combination produced long legibility distances for both letter heights, and only middle distance values for the directional arrow under day and night conditions for all participants. Previous research (e.g., Doughty, 1982) has suggested that optimal sign performance may be achieved when both legend and background are reflectorized by using a legend with a higher brightness value than the background material, as is the case for this color combination. This finding may explain why the purple and yellow color combination performed relatively well for the text legends when compared to the other color combinations. Just as the legibility results were mixed for this combination, so were the participant opinions. Half of the participants did not like this color combination, thought the color combination did not stand out well from the environment, and felt the sign was difficult to read due to less contrast and “blurring” of the letters. The other participants liked this color combination, thought this sign was noticeable, and felt the signs featured sufficient contrast. This color combination received a higher overall subjective preference rating (moderately to very readable).

Purple with Brilliant Yellow-Green Legend. The purple and brilliant yellow-green color combination produced legibility distances in the middle range of distances observed in the present study for both letter heights under day and night conditions for all participant groups. This color combination received a middle range preference rating (moderately to very readable) and primarily negative comments about readability. Most participants who expressed an opinion did not like this color combination, felt that the signs did not feature enough contrast within the signs or with the background environment, and found the test signs difficult to read due to letters "blending together." Two participants liked this color combination and found the legends easy to read.

Red, White and Blue Color Scheme. The red, white, and blue color combination produced mixed legibility results due to the split nature of the signs. When compared to the other color combinations, this color combination yielded long legibility distances for the top text legends, which were composed of red letters on white background, and middle distance values for the lower legends, which were composed of white letters on blue background. Seven participants stated that the blue portions of these test signs were more readable than the white portions, and one participant reported that the top legends were difficult to distinguish due to lack of contrast. Note also that participants sometimes mistook the red legends for black legends. Four participants stated that the white portions of the test signs were more readable than the blue portions, and one participant reported that the bottom legends were difficult to distinguish because the white letters "bled" into the closely located white portions of the sign face. Four participants liked this color combination and reported being able to see the sign colors from a distance. Five participants, however, did not like the split color combinations, and one of those participants called the split color combination "distracting." This color combination received a middle-range overall preference rating (moderately to very readable).

Brilliant Yellow-Green with Black Legend. The brilliant yellow-green and black color combination produced middle legibility distances for both the letter heights and long legibility distances for the directional arrow under day and night conditions for all participants. One participant mentioned that the "lettering was hard to pick out" on the test signs, and one older participant (S12) was unable to read the 100-mm (4-in) legend composed of series D letters. It is hypothesized that irradiation effects may have reduced the legibility of the text legends of these test signs. While the 125-mm (5-in) letter height produced longer distances than the 100-mm (4-in) letter height, previous research in this area (Allen and Straub, 1955) suggests that larger and/or wider letters may improve the legibility of text legends composed of this color combination. Most of the participants who had an opinion stated that this was a "good" color combination with "good" contrast; however, two participants did not like this color combination and found the test signs difficult to detect from a distance. This color combination received a middle to high overall preference rating (moderately to very readable).

Letter Design

Letter Height

The present study determined that the larger of the two letter heights used on the current EMERGENCY DETOUR highway sign standard, 125 mm (5 in), produced longer legibility distances than the smaller letter height, 100 mm (4 in), for all sign color combinations tested. The fact that the 125-mm (5-in) letter height produced longer legibility distances was no surprise since a larger letter size is easier to read and can be read from a longer distance. This longer reading distance extends the time in which a motorist may interpret and react to the information conveyed by a sign's message.

The present data also showed that the legibility results for each letter height as a function of sign color varied. Among the top performers for both letter heights were the coral and black, light blue and black, and purple and yellow color combinations. Other color combinations that produced longer legibility distances included the white on blue portion of the red, white, and blue color scheme, which performed well at the smaller letter height, and the light blue and blue and brilliant yellow-green and black color combinations, which performed well at the larger letter height. Note that the orange and black color combination was not among the top performers for either letter height. It is hypothesized that while orange and black is a standard and highly recognizable color combination, the other color combinations yielded longer legibility distances due to better contrast between the sign legend and background under all viewing conditions.

Letter Series

The present study determined that the series D letters (stroke width ratio = 0.16) produced longer legibility distances than the series C letters (stroke width ratio = 0.14) overall. Note, however, that examination of the data for each individual color combination revealed that the optimal letter series for a given color combination was dependent upon the letter height in question. Table 17 shows the letter series as a function of letter height that produced the longest legibility distances for each individual color combination.

The data indicated that the thicker, wider series D letters produced longer legibility distances in most cases. It is generally thought that for dark text on light backgrounds, thicker letters reduce the effects of irradiation, thus making the text legends more legible, and the present data generally support that theory. Light text on dark backgrounds usually requires thinner, narrower letters for better legibility, however, the present data do not necessarily support this theory. It is hypothesized that inconsistencies in sign fabrication, specifically reductions in letter spacing, may have reduced the legibility of the test signs by altering or amplifying the effects of irradiation. In some cases, the use of taller letters may have compensated for the effects of irradiation or inconsistent letter spacing, which may explain why the results differ for each of the four combinations of letter height and letter series. Further research is required to properly investigate these effects.

Note again that the coral and black and the light blue and black color combinations were among the top performers for both letter series. The orange and black color combination performed well overall with series C letters. In addition, the red, white, and blue color scheme and the purple and yellow color combination performed well overall with series D letters.

Table 17. Optimal letter series as a function of letter height for each color combination.

Color Combination	100-mm (4-in) Letter Height	125-mm (5-in) Letter Height
Coral and Black	*C/D	D
Coral and Blue	D	D
Coral and White	D	*C/D
Light Blue and Black	*C/D	D
Light Blue and Blue	D	D
Light Blue and Yellow	D	*C/D
Orange and Black	C	*C/D
Purple and Black	D	D
Purple and White	*C/D	C
Purple and Yellow	D	D
Purple and Brilliant Yellow-Green	D	D
Red on White -- Red, White, and Blue	D	-
White on Blue -- Red, White, and Blue	D	-
Brilliant Yellow-Green and Black	*C/D	D

*indicates that the legibility distances for series C and series D letters were not significantly different

Visibility Conditions

The present data revealed no significant difference between daytime and nighttime legibility distances overall for all sign color combinations tested, however, optimal sign color combinations under daytime and nighttime viewing conditions varied. Under daytime viewing conditions, color combinations that provided the participants with longer legibility distances, and thus greater advance warning or reaction distances, were the red, white, and blue (specifically white on blue), coral and black, light blue and black, brilliant yellow-green and black, and purple and yellow color combinations. It is hypothesized that these color combinations yielded greater daytime legibility distances because the colors were more distinct and conspicuous under the ideal daytime viewing conditions, and the contrasts between sign legend and background and sign and ambient environment were optimized. Participant preference ratings reflect similar findings, with the coral and black, light blue and black, brilliant yellow-green and black, purple and yellow, orange and black, coral and blue, and purple and white color combinations rated moderately to highly readable under day viewing conditions.

Under nighttime viewing conditions, the white on blue portion of the red, white and blue color combination provided the greatest legibility distances, which was most likely a function of the combined strong luminance contrast within this color combination and the retroreflective properties of the sign sheeting material. Note, however, that these results may have been affected by the inconsistencies in sign fabrication mentioned previously, specifically reductions in standard letter and line spacing, and the corresponding changes in irradiation effects may have altered the overall results for some color combinations. In addition, the number of participants was relatively small, and a larger sample size would be needed in order to obtain a proper assessment of the performance of these sign colors under daytime and nighttime viewing conditions. Note that participant preference ratings indicate that a large range of sign colors were deemed acceptable under night viewing conditions, with the red, white and blue, coral and black, light blue and black, light blue and blue, orange and black, purple and white, purple and yellow, and purple and brilliant yellow-green color combinations rated moderately to very highly readable under night viewing conditions.

Participant Age

The present data showed that legibility distances obtained for older participants were significantly shorter than those obtained for younger participants. This result was to be expected for several reasons. First, all of the younger participants demonstrated normal or better than normal visual acuity. Second, while half of the older participants demonstrated better than normal visual acuity, the remaining older participants demonstrated visual acuity sufficient to meet the legal driving requirement (20/40). Finally, older participants are affected by physiological changes that reduce both their visual and physical capabilities. The reduced legibility distances correspond to reduced decision and reaction time available to older drivers, which can lead to increased road incidents. Research (e.g., Mortimer and Fell, 1989) has suggested that traffic control devices should provide older drivers with more information and more time to respond than younger drivers, and the present data provide evidence to support that conclusion.

External Validity of Results

This study was a controlled field experiment on a closed test strip where the participants were required to perform only a partial driving task. The experimental conditions were optimally controlled, and all participants were exposed to exactly the same conditions and situations, weather and visibility conditions necessarily excepted. Lighting measurements and descriptions of weather conditions were collected to control for the effects of these variables.

This method of data collection raises the question of the external validity of the results; in other words, to what extent it is possible to generalize from the current conditions where test signs are observed without the normal driving task, to detecting traffic signs while driving in real traffic. A recent study (Jenssen, Moen, Brekke, Augdal, and Sjøhaug, 1996) incorporating a controlled field experiment led to the suggestion that the level of realism in the task of observing the traffic signs, as well as the way in which the participants are instructed and trained before the experiment, are probably important factors to overcome the problem of external validity.

Jenssen et al. (1996) noted that an indoor laboratory experiment would provide control over visibility and weather conditions, but external validity would be reduced. A field study in real traffic, however, may result in low reliability and low controllability due to many unpredictable factors and events. They concluded that validity can be low for any kind of evaluation method, making it difficult to generalize from one method to another.

CONCLUSIONS & RECOMMENDATIONS FOR FURTHER RESEARCH

Recall that the purpose of this study included the evaluation of the four currently unassigned background traffic sign colors, sign legend colors, and other design parameters to determine which would produce the best legibility distances under day and night conditions for both older and younger drivers, and the collection field data on the use of 0.610 m (24 in) by 0.72 m (30 in) signs featuring purple, light blue, coral, and brilliant yellow-green background. This evaluation of the human response was examined in terms of the legibility of the specified color and letter design parameters with respect to driver age and visual capabilities and in terms of the legibility of the specified color and letter design parameters under daytime and nighttime lighting conditions.

Color Combinations Producing The Best Legibility

The present study indicated that several different color combinations produced long legibility distances for the letter heights, letter series, and overall sign legends tested in Study 1. The following conclusions were made:

- The combinations that produced the best legibility results overall for all participants under both visibility conditions included the coral and black and the white on blue portion of the red, white, and blue color combinations.

- While the light blue and black color combination was not ranked in the highest grouping overall, this color combination produced high legibility results for the arrow icons and text legends individually, with consistently high results for each letter height as well.

- Purple and yellow, while not ranking in the highest grouping overall or for arrow icons, produced high legibility results for text legends overall and for each letter height.

- Five other color combinations, including coral and blue, light blue and blue, orange and black, purple and white, and brilliant yellow-green and black, ranked highly for arrow icons only, however, only the light blue and blue and the brilliant yellow-green and black color combinations also produced high legibility results for the text legends, specifically the 125-mm letter height.

- The color combinations that produced the best legibility results for the 100-mm letter height under day and night conditions for all participant groups included the following: 1) the white on blue portion of red, white, and blue; 2) purple and yellow; 3) coral and black; and 4) light blue and black.

- The color combinations that produced the best legibility results for the 125-mm letter height under day and night conditions for all participant groups included: 1) coral and black; 2) light blue and black; 3) purple and yellow; 4) light blue and blue; and 5) brilliant yellow-green and black.

- The color combinations that produced the best legibility distances for series C letters under day and night conditions for all participant groups included the following: 1) coral and black; 2) orange and black; and 3) light blue and black.

- The color combinations that produced the best legibility distances for series D letters under day and night conditions for all participant groups included the following: 1) the red on white portion of red, white, and blue; 2) purple and yellow; 3) white on blue portion of red, white, and blue; 4) light blue and black; and 5) coral and black.

Note that the orange and black color combination is not listed consistently, thus indicating that there are indeed other color combinations that perform better than the orange and black color combination in terms of legibility of all legend elements.

The participants' subjective assessment of sign legibility indicated that the orange and black color combination received the highest overall preference rating for readability, however, the coral and black, the light blue and black, the purple and white, and the purple and yellow color combinations were also rated highly and were not statistically different. Thus, these color combinations were most preferred for traffic sign readability by participants in this study.

The results indicated an overall benefit for all drivers in terms of legibility when employing signs featuring the coral and black, light blue and black, and purple and yellow color combinations to convey directional information under both day and night viewing conditions. The coral and black and the light blue and black color combinations ranked highly for both letter heights and the directional arrow, hence their inclusion in this list of best color combinations for overall legibility. Although the purple and yellow color combination did not rank highly in legibility for the directional arrow, this color combination did rank high in terms of performance relative to letter height and the subjective assessment of legibility. It is expected that the purple and yellow color scheme's distinctness and high negative contrast will lend itself well to greater conspicuity in a normal traffic environment, thus this color combination is included for further investigation as well. The results also indicate that participants representative of the driving population have identified these color combinations as being highly legible when compared to the other color combinations specified.

The other color combinations listed above, including red, white, and blue, light blue and blue, brilliant yellow-green and black, and purple and white, were removed from the list of best color combinations for overall legibility for a variety of reasons. While the red, white, and blue color combination produced good legibility results for the white on blue lower legend and the arrow icon, the red on white upper text legend did not produce comparable results, the combination was rated very poorly by participants in terms of overall legibility, and many participants disliked the split color combination. In addition, the red, white, and blue color scheme was only tested with the 100-mm (4-in) letter height to match the scheme currently under consideration in Northern Virginia. It was decided to forego further testing with this color scheme at the current time since further experimentation of this color scheme with the 125-mm (5-in) letter height would require a significantly larger recommended sign size (to fit the Emergency Detour message within borders) should that color combination prove to yield the best on-road results. The light blue and blue, while performing well in terms of the larger letter height and the arrow icons, did not perform as well overall or in terms of the smaller letter height and overall text. The brilliant yellow-green and black color combination, while producing one of the larger legibility distances for the directional arrow and a high subjective preference rating, failed to perform as well for text legends overall, an unacceptable result for a sign that may be used to convey text information only. Finally, the purple and white combination was ranked highly in terms of participants' subjective assessment of legibility, but the legibility distance data showed that this color combination did not perform well overall.

Summary and Recommendations for Further Research

Based on the results of this study, and related findings from previous research outlined in this report, the following conclusions and recommendations were made:

1. Upon comparison with standard orange and black traffic control signs, the results indicated a benefit for drivers, in terms of legibility, when traffic control signs employ a color combination other than standard orange and black.

2. The results indicated that the coral and black, light blue and black, and purple and yellow color combinations should be further investigated in an on-road test to compare the conspicuity of these color combinations against the standard orange and black color combination when used to convey directional or incident management information, such as EMERGENCY DETOUR.

3. The results indicated a benefit, in terms of legibility, for drivers when the traffic signs in question employed the 125-mm (5-in) letter height; thus, the signs to be tested in the on-road test should employ 125-mm (5-in) letters for both the upper and lower legends.

4. Results indicated a benefit, in terms of legibility, for drivers when signs composed of coral and black, light blue and black, and purple and yellow employed series D letters (stroke width ratio = 0.16) in the 125-mm (5-in) letter height. Thus, the signs to be tested in the on-road test should employ series D letters for both the upper and lower legends.

CHAPTER 4. METHOD AND RESULTS OF CONSPICUITY AND UNDERSTANDABILITY EVALUATION OF SIGN DESIGN PARAMETERS

The second part of this research, Study 2, is discussed in this chapter. Study 2 was an on-road field study investigating the conspicuity and effectiveness of the three sign color combinations (coral and black, light blue and black, and purple and yellow) and corresponding letter designs (125-mm, Series D letters) that resulted in the best legibility distances in Study 1, and the standard black on orange sign color combination and corresponding letter design currently used for construction detours and emergency incident-related detours, when overlaid with an existing construction detour.

METHODS AND MATERIALS

Experimental Design

A 4 (Sign Color) x 2 (Age) x 2 (Visibility Condition) between factor design was utilized for this study. The general assignment of participants is shown in Table 18. Drivers were included in one of two age groupings, Younger or Older drivers. Male and female drivers within those groupings were randomly assigned to one visibility condition, either Day or Night. Participants with varying levels of color vision deficiency were also randomly assigned between day and night conditions. Note that daytime viewing conditions included both clear conditions and cloudy or partly cloudy conditions, to which participants were randomly assigned. Each participant was shown one test sign configuration (or Sign Color Combination), and each participant was exposed to one visibility condition, as indicated in Table 18 (see Appendix R for detailed description of participant assignments). The same experimental detour route, located alongside an existing work zone detour in Mecklenburg County, Virginia, was used for all participants (see Appendix S for a map of the route).

Table 18. Experimental assignment of participants in Study 2.

	Younger Drivers		Older Drivers		Totals
Sign Color Combination	**Daytime**	**Nighttime**	**Daytime**	**Nighttime**	
Black on Orange - Baseline	5	4	4	2	15
Yellow on Purple	4	6	4	5	19
Black on Light Blue	4	5	6	2	17
Black on Coral	6	5	6	2	19
	19	20	20	11	
TOTALS	39		31		70

Independent Variables

The independent variables in this experiment included the following:

Sign Color Combination. The three experimental color combinations included purple with yellow legend, light blue with black legend, and coral with black legend. These color combinations were chosen based on the results of Study 1. The black on orange color combination was tested as a baseline for comparison.

Age. Two age groups of participants, or drivers, were used: younger drivers (18-34 years) and older drivers (54-75 years). Note that, as with other on-road driving studies, there was difficulty recruiting older drivers to participate in the night driving condition.

Visibility Condition. Participants drove either during daytime or at night. Thirty-nine of the participants observed the test signs during daytime sessions. Daytime test sessions began no sooner than one hour after sunrise. During the course of the study, all signs were observed under both clear skies and cloudy/partly cloudy conditions. Thirty-one of the participants observed the test signs during nighttime sessions, with only the low-beam headlights of the test vehicle to illuminate the test signs. Nighttime test sessions began no sooner than one-half hour after sunset. All data collection occurred in fair weather, i.e., no precipitation was falling.

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 (see Appendix R for detailed description of participant assignments).

Color Vision Deficiency. Visual ability was controlled such that at least one participant for each sign color combination demonstrated some level of color vision deficiency. Eight participants demonstrated normal color vision using the Titmus® II vision tester, 33 participants demonstrated a mild level of deficiency, and 29 participants failed the color vision screening (see Appendix R for description of participants). The fact that a majority of the participants demonstrated some level of color vision deficiency may be due to the use of an older motorized vision tester whose test slides may be beginning to show signs of aging. All participants who volunteered and met all of the other screening criteria were asked to participate since this criteria was not used as a basis to determine eligibility to participate.

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.

The videotape record provided by the cameras' views was time-stamped and synchronized with the computer data stream so that post-test data reduction and data set merging could be performed in the laboratory. All vehicle data collection records were time-stamped to an accuracy of +/- 0.1 seconds. The specific measures collected were as follows:

Average Vehicle Velocity/Velocity Variance. Research indicates velocity maintenance to be a sensitive measure of changes in the amount of attention demanded by secondary driving tasks (Monty, 1984). A change in vehicle velocity can also be used to indicate the point where a driver receives information about detour or speed limit change information.

Late Braking Reaction. Braking behavior can also provide a sensitive measure of performance (Monty, 1984). If drivers are inattentive, the brake must be depressed harder and the resulting deceleration is greater than in a normal attention situation. In addition, an abrupt maneuver can be indicative of a driver receiving or processing information late about an upcoming maneuver. A late reaction was operationally defined by a brake position found to be 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 and ended when the experimental vehicle past the sign.

Longitudinal Acceleration/Deceleration Measures and Braking Data. The pattern of acceleration and braking data is an indication of driver inattention to the forward roadway.

Lateral Acceleration Measures. Abrupt lateral maneuvers, such as large steering reversals, are indicative of a vehicle that is off the center lane track due to driver inattention. Lateral acceleration measures are highly correlated to driver steering input and are therefore used to highlight large magnitude corrections.

Steering Wheel Position Variance. Research has shown that changes in driver steering behavior occur when driver attention changes (Wierwille and Gutman, 1978). In normal, low-attention circumstances, drivers make continuous, small steering corrections to correct for roadway variance and driving conditions. These corrections typically range from two to six degrees. As attention or workload demands increase, the number of these corrections decreases, requiring a larger input to correct the vehicle's position. Therefore, an increase in the variance of steering wheel position indicates high attention or workload requirements.

Number of Wrong and Missed Turns. The number of wrong turns is an indication of whether the signs are being detected, recognized, and understood by the driver. A wrong turn event was defined as a turn taken when no directional information was provided to indicate a required turn. A missed turn 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. This data was collected by the experimenter.

Subjective Acceptance and Preference Measures. This data was collected via a subjective questionnaire to assess the driver's impressions and preferences about the TEST DETOUR signs.

Participants

Ninety-six drivers were to have participated in this study. However, due to (1) a limited test period of one month associated with the impending removal of the workzone detour and (2) recruitment limitations in the test area, 70 drivers actually participated in this study. Thirty-nine participants were between the ages of 18 and 34 (younger drivers), and 31 participants were between the ages of 54 and 75 (older drivers). Drivers were recruited through advertisements in local newspapers and flyers posted at local merchants in the Mecklenburg County area. Participants received $25 for participating in this study for approximately one hour of experiment time.

Each participant was required to: (1) be a licensed driver; (2) drive a minimum of twice a week in Mecklenburg County, Virginia, or the surrounding area; (3) pass a health screening questionnaire; and (4) have a minimum of 20/40 visual acuity, wearing corrective lenses if necessary. In addition, participants were screened for color vision deficiencies, and participants were randomly assigned to each sign color combination based on a demonstrated deficiency.

Apparatus

The primary apparatus used in the study were: (1) an illuminance meter; (2) a vision tester; (3) the automobile; (4) the test signs located along the test route; and (5) the post-test questionnaire. These are described in the following sections.

Illuminance Meter

An Extech Instruments Digital Light Meter was used to obtain illuminance measurements of the ambient lighting conditions during the data collection sessions. The measuring range for this device is 0.0 to 50,000 lux (0.0 to 5,000 foot-candelas).

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, however, it was not able to classify as to type.

Automobile

A 1995 Oldsmobile Aurora was used as the experimental vehicle for all participants. The instrumentation in the vehicle provided the means to 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 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 form for analysis. A detailed description of the components of the vehicle is in Appendix T.

Experimental Sign Design

There were three experimental sign design configurations in addition to the orange with black legend baseline for a total of four color combinations. The signs read "TEST" on the first line and "DETOUR" on the second line. The lettering on the coral and black, light blue and black, and purple and yellow test signs was made up of Series D letters (refer to Appendix D for information regarding letter series). The overall dimensions for each sign were 0.609 m (24 in) tall by 0.762 m (30 in) wide, as is the standard for the black on orange EMERGENCY DETOUR signs currently used. Remaining specifications are shown in Figure 15.

A photograph of the experimental sign color combinations is shown in Figure 16. The actual Commission International d'Eclairge (CIE) Notations for the background and legend colors are shown in Table F as specified in the *Standard Highway Color Specifications* (U. S. Department of Transportation, 1969). Note that, as in Study 1, the coral color used is not the same as that specified in the *Standard Highway Color Specifications* (U. S. Department of Transportation, 1969), however, it is extremely close. The reason for the discrepancy is that the specified coral ink was not readily available from the manufacturer. The coral-colored ink specified for this study, as well as the purple- and light blue-colored inks, were specially formulated for this study. Note that neither the test colors nor the colors used on the existing detour signs along the test route were fluorescent. At the time of testing, the test colors were not all available in fluorescent versions. Due to this fact, testing was only conducted for colors that could be produced in similar materials.

The background colors for all of the test signs, as well as the existing orange and black detour signs, were fabricated by traditional silk screening. All black legends and borders were applied using non-reflective black tape. The highway yellow legends and borders were applied using yellow-colored Scotchlite™ Diamond Grade Reflective sheeting tape. The colored inks, Scotchlite™ Transparent Process Color by 3M, for both test signs and existing detour signs were applied to aluminum sheeting via the 3M Company's Scotchlite™ Diamond Grade Reflective sheeting material.

There were 18 experimental signs posted along the route. Each sign panel was supported on a standard sign post, and oriented approximately perpendicular to the direction of travel, facing the observation vehicle, as is normal practice. The signs were mounted 2.13 m (7 ft) from the ground to the bottom edge of the sign with the exception of two cases in which test signs were mounted below existing traffic or street signs on a single post. Sign supports were located on the right shoulder of the road, approximately 3.66 m (12 ft) from the edge of the travel lane, as specified by the MUTCD.

Post-test Questionnaire

The post-test questionnaire employed gather subjective opinion data is included in Appendix U. The first three questions on the survey asked the driver to *rate* the test signs he or she had observed along the test route in terms of visibility, ease of identifying and understanding the directional information, and usefulness of the sign information. It is important to note that these questions asked the driver to make a judgment regarding only the sign he or she observed; that is, the drivers had only seen one sign color to this point and could not judge the sign color as it compared to the other experimental sign colors.

Survey questions 4, 5, and 6 asked the drivers to *rank* the four sign colors based on two redundant information sources. The first source included 7.5 cm x 12.5 cm samples of the background sign colors (without contrasting legend color) on Scotchlite Type 3 high intensity grade sheeting (described as having a "honeycomb" appearance). The second source consisted of 8 cm x 8 cm Polaroid photographs (taken with the flash on), one of each of the four experimental sign colors. Drivers were asked to rank the signs in terms of visibility, readability, and overall preference. The pictures were taken during the daylight hours (late afternoon) at a distance of approximately one meter. It is important to note that 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 or other external light sources 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.

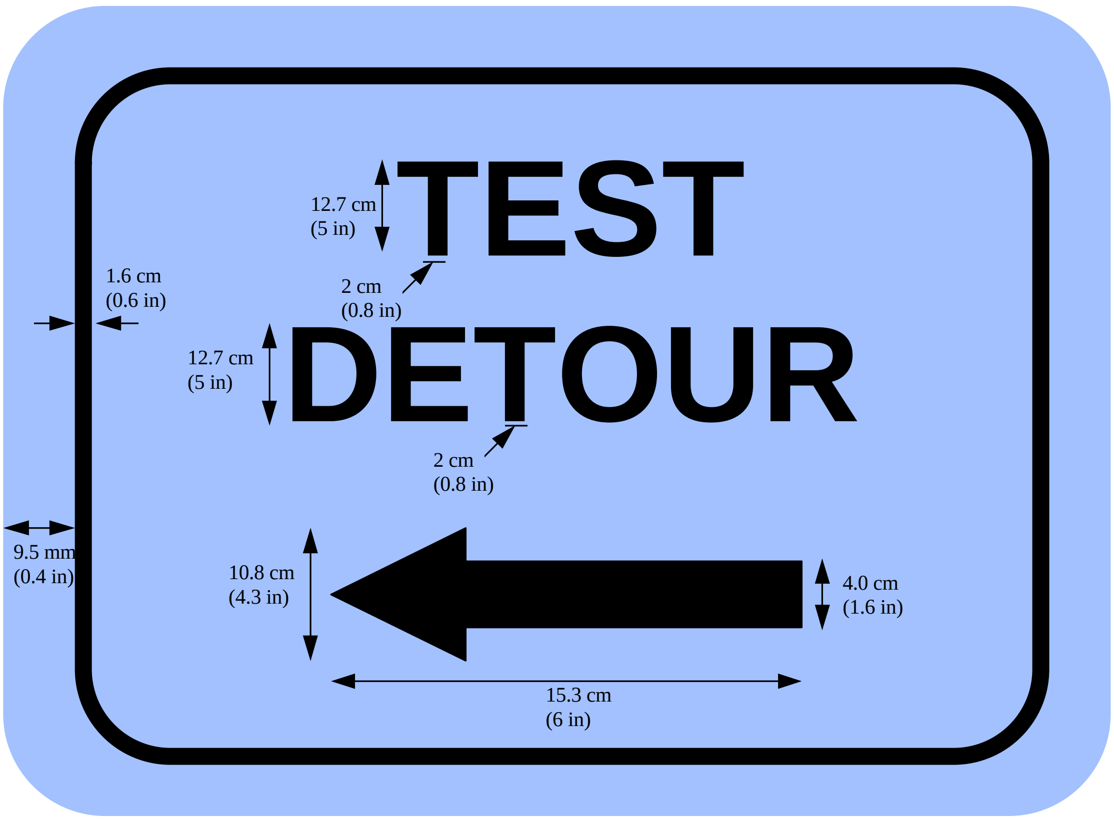


Figure 15. Experimental TEST DETOUR sign specification.

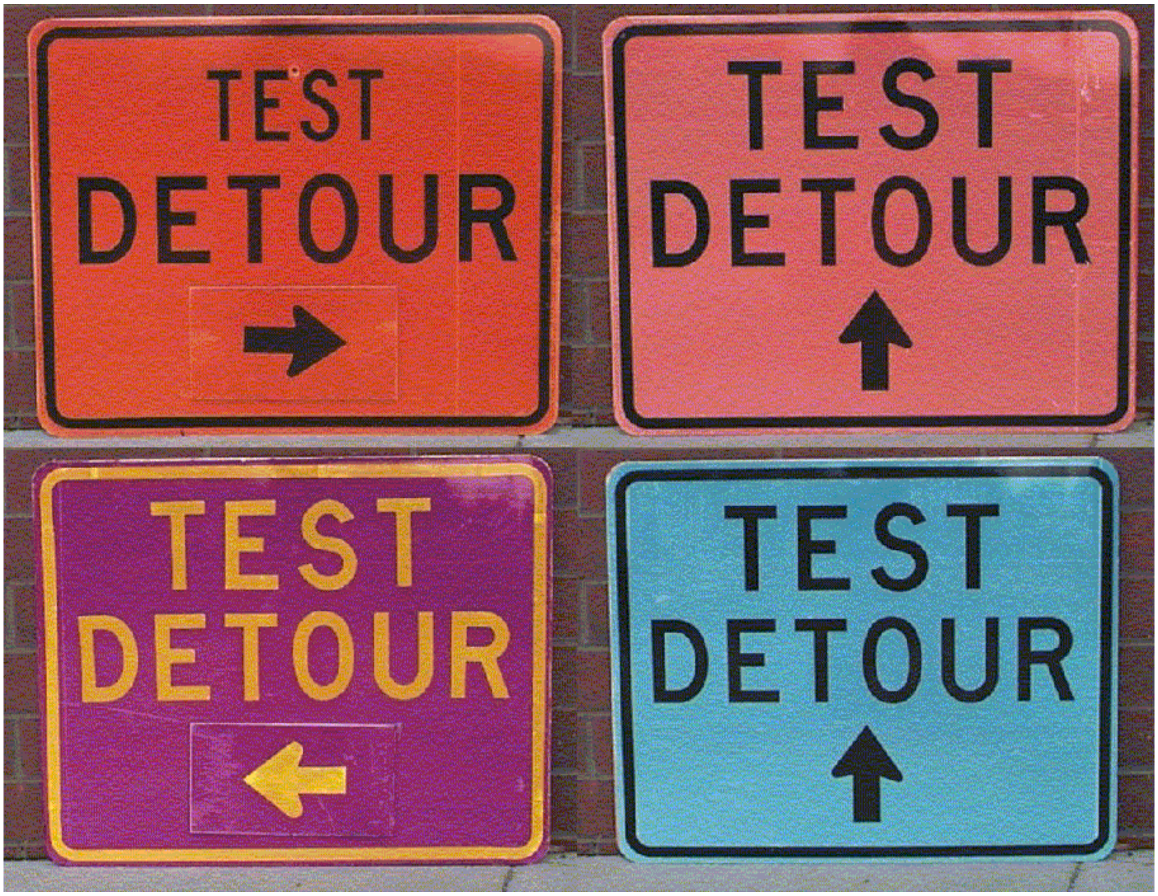


Figure 16. The experimental test signs for Study 2 (clockwise from top left: orange & black, coral & black, light blue & black, and purple & yellow).

Procedure

Participant Screening and Training

Participants were initially screened over the telephone regarding age, gender, driving frequency, and general health (Appendix V). If participants were eligible, times were scheduled for testing. Participants were instructed to meet experimenters at the Chase City Police Department, in Chase City, Virginia. Upon arrival, the participant was given an overview of the study, and he or she was asked to review and complete the informed consent form (Appendix W). Next, he or she was asked to complete the health screening process (i.e., complete part 2 of questionnaire, Appendix V). In addition, he or she was given a simple vision test and a color vision test (Appendix L) using the Titmus® II vision tester. After these tasks were completed, the participant was escorted to the test vehicle.

While the car was in park, the first experimenter reviewed general information concerning the operation of the test vehicle (e.g., lights, seat adjustment, mirrors, windshield wipers; see Appendix Y). (Also at this time, the second experimenter made sure that the vehicle's windshield was cleaned prior to the beginning to the test session.) The participant was then asked to operate each control and set it for his/her driving comfort. Night drivers were instructed to use the low-beam halogen headlights during nighttime driving conditions. When the participant felt comfortable with the controls, the experimenter briefly described the driving task. To allow the participant to become familiar with the handling of the vehicle, the drivers maneuvered the vehicle along a practice route. No test signs were mounted along the practice route. Once the driver completed the practice session, he/she was asked if he/she felt comfortable with the car. If the answer was "no," the practice run was repeated. Drivers were allowed as many practice runs as desired in order to feel comfortable with the vehicle. In addition, the vehicle's windshield was cleaned prior to each testing session. When the driver indicated that he/she felt comfortable with the car, the test run.

Data Collection Techniques

The data for this experiment were collected both manually and by computer. All manually collected data were later entered into a microcomputer for analysis. All data were entered into a spreadsheet/statistical data sheet format for analysis and archival purposes.

The experimental protocol required two experimenters as well as the participant to be in the vehicle. The experimenter seated in the front passenger seat gave initial navigational instructions, served as the safety officer using the emergency brake as needed, 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 or pedestrians or animals on or crossing the roadway, 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 (refer to Appendix X for experimenter protocols.)

At the beginning of the test route, the participant was instructed to look for and follow the signs that read "TEST DETOUR." The participant was told that these signs marked a predetermined route of approximately 12 miles in length. The participant was 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 taken. While following the directions provided by the signs, the participant was 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/her back to the prescribed route.

The test route and data collection began in Chase City, Virginia, on Highway 92 and ended at the rural intersection of state route 698 and Highway 49 (see Appendix S). The test route was approximately 19.3 km (12 mi.) long and overlapped with an existing detour for a construction work zone located on state route 49. The roadways along the entire test route were two-lane roads, some portions with marked lanes and some without, and with few sources of illumination other than occasional private homes or businesses once outside of the business section of Chase City.

The first 2 km (1.25 mi.) of the test route overlapped the existing car and truck detour route. The next 10.07 km (6.25 mi.) of the test route overlapped the existing car detour route. The remaining 7.24 km (4.5 mi.) of the test route employed only the experimental signs. The number of experimental signs matched the number of existing detour signs per unit of distance.

Signs were posted in both urban and rural settings. The first three sign posts were placed in a business section of Chase City, Virginia. All other sign posts were placed in rural settings in Mecklenburg County. A total of 23 sign post locations were used to post the existing detour signs and the experimental signs along the 19.3-km test route.

Photometric measurements of ambient light and weather conditions were also recorded at the beginning of each testing session (see Appendix Y).

Debriefing

Following completion of the test run, participants were driven back to the meeting place, i.e., the Chase City Police Department, where an experimenter administered the post-test questionnaire (see Appendix U). Drivers were then debriefed and paid for their time. The total time for the experiment was approximately one hour.

RESULTS

All statistical analyses were conducted using the SAS® 6.12 software package. Due to missing or unbalanced experimental cells (typical of field experiments), all ANOVAs were conducted using the GLM procedure. For this experiment, a 0.05 significance level was used (95% probability that the results reported reflect actual differences). Non-parametric tests were performed where appropriate.

Driving Performance Variables

Late Braking Maneuvers

A late braking maneuver was operationally defined as an incident requiring a brake position more than 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 and ended when the experimental vehicle passed the sign.

Only one sign event, shown in Appendix S at site 20, had enough late braking maneuvers to evaluate (three other sign events resulted in one late braking maneuver each). Sixteen of 70 participants demonstrated late reactions. A chi-square test was conducted on the braking data using the 4 x 2 matrix shown in Table 19. The differences between sign colors were not significant, $i^2(3,N=70) = 5.866$, $p = 0.118$ (note that the chi-square statistic was not adjusted to account for expected frequency counts less than 5; see Appendix Z, Table Z-1 for pairwise comparisons of sign colors). Differences in late braking maneuvers as analyzed by age, visibility condition, and the interaction between age and visibility condition, did not approach significance.

Table 19. Frequency of late braking maneuvers.

Sign Color Combination	No Late Reaction Observed	Late Reaction Observed
Orange w/ black legend	10	5
Purple w/ yellow legend	17	2
Light Blue w/ black legend	15	2
Coral w/ black legend	12	7

Other Driving Performance Variables

Data analysis performed on the other driver performance variables measured (Average Vehicle Velocity/Velocity Variance, Longitudinal Acceleration/Deceleration Measures and Braking Data, Lateral Acceleration Measures, Steering Wheel Position Variance) showed no significant differences for an analysis by sign color, age, or visibility condition. This outcome may be a result of a relatively small effect size combined with the high variability in driving performance measures that occur in field data.

Analysis of Wrong and Missed Turns

Assessment For Sign Color

Wrong and missed turns were analyzed together as turn errors. Table 20 shows the frequency of correct turns and turn errors analyzed by sign color. 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. Note that there were no incorrect turn events (wrong or missed turns) for the light blue with black legend test detour sign.

Table 20. Overall frequency of turn errors by sign color combination.

Sign Color Combination	Correct Turns	Incorrect Turns
Orange w/ black legend	336	9
Purple w/ yellow legend	431	6
Light Blue w/ black legend	391	0
Coral w/ black legend	431	6

A 4 x 2 chi-square test was conducted on the data contained in Table 20 to determine if there was a difference between the number of correct and incorrect turns for each sign color. There was a significant difference between sign colors, $i^2(3,N=1610) = 9.759$, $p = 0.021$ (note that the chi-square statistic was not adjusted to account for expected frequency counts less than 5). A series of pairwise chi-square tests revealed that the black on light blue sign was the only sign color combination to result in significantly fewer turn errors than the orange sign, and tended to result in fewer turn errors than the purple and coral signs (see Appendix Z, Table Z-2;).

Assessment For Age

A chi-square test was conducted on the incorrect turn data contained in Table 21 to determine if there was a significant difference for each sign color in the number of incorrect turns by younger and older drivers. The results show that there was not a significant difference between the age groups, $i^2(1,N=1610) = 0.096$, $p = 0.757$, indicating that younger and older drivers made a similar number of incorrect turns for each sign color.

Table 21. Frequency of turn errors by driver age and sign color combination.

Sign Colors	Younger Drivers	Older Drivers
Orange w/ black legend	4	5
Purple w/ yellow legend	4	2
Light blue w/ black legend	0	0
Coral w/ black legend	3	3

Assessment For Visibility Condition

A chi-square test was conducted on the data in the 4 x 2 matrix in Table 22 to determine if there was a difference between the daytime and nighttime driving conditions for each sign color. The results indicate that there is a significant difference between daytime and nighttime drivers, $i^2(1,N=1610) = 4.320$, $p = 0.038$.

To find the differences in turn data for daytime drivers, a chi-square test was performed on the 4 x 2 matrix in Table 23 that revealed a significant difference, $i^2(3,N=897) = 9.713$, $p = 0.021$ (note that the chi-square statistic was not adjusted to account for expected frequency counts less than 5). A paired comparison of the four sign color combinations for daytime drivers revealed that the light blue sign tended to result in significantly fewer incorrect turns than the traditional orange sign (see Appendix Z, Table Z-3).

Table 22. Frequency of turn errors by visibility condition and sign color combination.

Sign Colors	Daytime	Nighttime
Orange w/ black legend	5	4
Purple w/ yellow legend	1	5
Light blue w/ black legend	0	0
Coral w/ black legend	1	5

Table 23. Frequency of correct turns and incorrect turns for daytime drivers.

Sign Colors	Correct Turns	Incorrect Turns
Orange w/ black legend	202	5
Purple w/ yellow legend	183	1
Light blue w/ black legend	230	0
Coral w/ black legend	275	1

To determine where the differences in turn data were for nighttime drivers, a chi-square test was performed on the 4 x 2 matrix in Table 24. No significant differences were found between the sign colors, $i^2(3,N=713) = 4.942$, $p = 0.176$ (note that the chi-square statistic was not adjusted to account for expected frequency counts less than 5).

Table 24. Frequency of correct turns and incorrect turns for nighttime drivers.

Sign Colors	Correct Turns	Incorrect Turns
Orange w/ black legend	134	4
Purple w/ yellow legend	248	5
Light blue w/ black legend	161	0
Coral w/ black legend	156	5

Driver Preference Data

For survey questions 1, 2, and 3, the participant only rated the sign he or she observed while driving (refer to the section "Post-test Questionnaire" and Appendix U). Since the number of participants who viewed each sign color was unequal, the number of drivers rating each sign was unequal. Therefore, the number of drivers (or observations) making each rating is specified in the tables as "N = *number*. " Means and standard deviations are also specified.

Survey Question #1: Rating Sign Visibility

This question asked drivers to rate the visibility of the experimental TEST DETOUR sign that they saw on the test route on a Likert-type scale of one to five, with one meaning "not visible" and five meaning "extremely visible" (see Appendix U). An ANOVA was completed for question 1, with three factors of interest, including sign color combination (SGNCLR), age (AGE), and visibility condition (VISCON) (see Appendix Z, Table Z-4).

For the assessment for sign color, Table 25 presents the mean scores for each sign color combination. An analysis of variance for sign color (see Appendix Z, Table Z-4) revealed that the ratings were not significantly different from one another, $F(3,54) = 1.55$, $p = 0.2121$.

Table 25. The mean ratings for survey question 1.

Sign Colors	Mean (STD)*	# of Obs.
Orange w/ black legend	3.73 (1.0328)	N=15
Purple w/ yellow legend	4.05 (0.7799)	N=19
Light blue w/ black legend	4.06 (0.8269)	N=17
Coral w/ black legend	3.74 (0.6534)	N=19

* 1 = not visible, 5 = extremely visible

For the assessment for age, Table 26 presents the mean scores for each sign color combination for younger and older drivers. An analysis of variance for age-related differences (see Appendix Z, Table Z-4) revealed that the ratings by younger and older drivers were not significantly different for each sign color, F(1,54) = 1.78, p = 0.1879.

Table 26. The mean ratings for survey question 1 by age.

Sign Colors	Younger Drivers Mean (STD)	STD	Older Drivers Mean (STD)	STD
Orange w/ black legend	3.33 (1.0000)	N=9	4.33 (0.8165)	N=6
Purple w/ yellow legend	4.10 (0.8756)	N=10	4.00 (0.7071)	N=9
Light blue w/ black legend	3.78 (0.6667)	N=9	4.34 (0.9161)	N=8
Coral w/ black legend	3.73 (0.4671)	N=11	3.75 (0.8864)	N=8

* 1 = not visible, 5 = extremely visible

For the assessment for visibility condition, Table 27 presents the mean scores for each sign color combination for daytime and nighttime drivers. An analysis of variance for differences in ratings between daytime versus nighttime drivers (see Appendix Z, Table Z-4) revealed that daytime drivers ranked the signs they saw as significantly more visible (mean = 4.18, STD = 0.7208) than the nighttime drivers (mean = 3.55, STD = 0.8099), F(1, 54) = 11.23, p = 0.0015.

No significant differences were found for the two-way age by sign color, visibility condition by sign color, or age by visibility condition interactions, and no significant difference was found for the three-way age by visibility condition by sign color interaction.

Table 27. The mean ratings for survey question 1 by visibility condition.

Sign Colors	Day Mean (STD)	# of Obs.	Night Mean (STD)	# of Obs.
Orange w/ black legend	4.00 (0.8660)	N=9	3.33 (1.2111)	N=6
Purple w/ yellow legend	4.63 (0.5175)	N=8	3.64 (0.6742)	N=11
Light blue w/ black legend	4.30 (0.8233)	N=10	3.71 (0.7559)	N=7
Coral w/ black legend	3.92 (0.5149)	N=12	3.43 (0.7868)	N=7

* 1 = not visible, 5 = extremely visible

Survey Question #2: Rating Sign Readability and Understandability

This question asked drivers to rate presentation of directional information on the experimental TEST DETOUR sign that they saw while driving. The Likert-type rating scale ranged from one to five, with one meaning “not easy” to identify and five meaning “extremely easy” to identify (see Appendix U). An ANOVA was completed for question 2, with three factors of interest, including sign color combination (SGNCLR), age (AGE), and visibility condition (VISCON) (see Appendix Z, Table Z-5).

For the assessment for sign color, Table 28 presents the mean scores for each sign color combination. An analysis of variance for sign color (see Appendix Z, Table Z-5) revealed that the ratings were not significantly different from one another, $F(3,54) = 1.11$, $p = 0.3532$.

Table 28. The mean ratings for survey question 2.

Sign Colors	Mean (STD)	# of Obs.
Orange w/ black legend	4.07 (1.0328)	N=15
Purple w/ yellow legend	4.11 (0.8753)	N=19
Light blue w/ black legend	4.24 (0.7524)	N=17
Coral w/ black legend	4.00 (0.8165)	N=19

* 1 = not easy, 5 = extremely easy

For the assessment for age, Table 29 presents the mean scores for each sign color combination for younger and older drivers. An analysis of variance for age-related differences (see Appendix Z, Table Z-5) revealed that the ratings by younger and older drivers were not significantly different for each sign color, $F(1,54) = 1.44$, $p = 0.2361$.

For the assessment for visibility condition, Table 30 presents the mean scores for each sign color combination for daytime and nighttime drivers. An analysis of variance for visibility condition (see Appendix Z, Table Z-5) revealed that the daytime drivers rated the directional information on the signs they saw as significantly easier to identify and understand (mean = 4.49, STD = 0.6014) as compared to nighttime drivers (mean = 3.61, STD = 0.8823), $F(1,54) = 22.47$, $p = 0.0001$.

Table 29. The mean ratings for survey question 2 by age.

	Younger Drivers		Older Drivers	
Sign Colors	Mean (STD)	# of Obs.	Mean (STD)	# of Obs.
Orange w/ black legend	4.00 (1.000)	N=9	4.17 (1.1690)	N=6
Purple w/ yellow legend	3.90 (1.1005)	N=10	4.33 (0.5000)	N=9
Light blue w/ black legend	3.89 (0.7817)	N=9	4.63 (0.5175)	N=8
Coral w/ black legend	3.91 (0.7006)	N=11	4.13 (0.9910)	N=8

* 1 = not easy, 5 = extremely easy

Table 30. The mean ratings for survey question 2 by visibility condition.

Sign Colors	Day Mean (STD)	Day # of Obs.	Night Mean (STD)	Night # of Obs.
Orange w/ black legend	4.67 (0.5000)	N=9	3.17 (0.9832)	N=6
Purple w/ yellow legend	4.63 (0.7440)	N=8	3.73 (0.7862)	N=11
Light blue w/ black legend	4.40 (0.6992)	N=10	4.0 (0.8165)	N=7
Coral w/ black legend	4.33 (0.4924)	N=12	3.43 (0.9759)	N=7

* 1 = not easy, 5 = extremely easy

No significant differences were found for the two-way age by sign color, visibility condition by sign color, or age by visibility condition interactions, and no significant difference was found for the three-way age by visibility condition by sign color interaction.

Survey Question #3: Rating Sign Usefulness for Providing Temporary Directional/Detour Information?

This question referred to the experimental TEST DETOUR sign that drivers saw on the driving route. Drivers were asked to rate the sign they saw on a Likert-type scale of one to five, with one meaning the information was "not useful" and five meaning the information was "extremely useful." An ANOVA was completed for question 3, with three factors of interest, including sign color combination (SGNCLR), age (AGE), and visibility condition (VISCON) (see Appendix Z, Table Z-6).

For the assessment for sign color, Table 31 presents the mean scores for each sign color combination. An analysis of variance for sign color (see Appendix Z, Table Z-6) revealed that the ratings were not significantly different from one another, $F(3,54) = 1.05$, $p = 0.3779$.

Table 31. The mean ratings for survey question 3.

Sign Colors	Mean (STD)	# of Obs.
Orange w/ black legend	3.93 (0.7988)	N=15
Purple w/ yellow legend	3.89 (0.8753)	N=19
Light blue w/ black legend	3.94 (0.8993)	N=17
Coral w/ black legend	3.63 (1.0116)	N=19

* 1 = not useful, 5 = extremely useful

For the assessment for age, Table 32 presents the mean scores for each sign color combination for younger and older drivers. An analysis of variance for age-related differences (see Appendix Z, Table Z-6) revealed that the ratings by younger and older drivers were not significantly different for each sign color, $F(1,54) = 1.92$, $p = 0.1718$.

Table 32. The mean ratings for survey question 3 by age.

Sign Colors	Younger Drivers Mean (STD)	Younger Drivers # of Obs.	Older Drivers Mean (STD)	Older Drivers # of Obs.
Orange w/ black legend	3.67 (0.8660)	N=9	4.33 (0.5164)	N=6
Purple w/ yellow legend	3.90 (0.9944)	N=10	3.89 (0.7817)	N=9
Light blue w/ black legend	3.56 (0.7265)	N=9	4.38 (0.9161)	N=8
Coral w/ black legend	3.73 (0.7862)	N=11	3.50 (1.3093)	N=8

* 1 = not useful, 5 = extremely useful

For the assessment for visibility condition, Table 33 presents the mean scores for each sign color combination for daytime and nighttime drivers. An analysis of variance by visibility condition (see Appendix Z, Table Z-6) revealed that the ratings were not significantly different for daytime drivers as compared to nighttime drivers, $F(1,54) = 1.36$, $p = 0.2483$.

No significant differences were found for the two-way age by sign color, visibility condition by sign color, or age by visibility condition interactions, and no significant difference was found for the three-way age by visibility condition by sign color interaction.

Table 33. The mean ratings for survey question 3 by visibility condition.

Sign Colors	Day Mean (STD)	Day # of Obs.	Night Mean (STD)	Night # of Obs.
Orange w/ black legend	4.11 (0.6009)	N=9	3.66 (1.0328)	N=6
Purple w/ yellow legend	4.25 (0.7071)	N=8	3.64 (0.9244)	N=11
Light blue w/ black legend	4.00 (0.9428)	N=10	3.86 (0.8997)	N=7
Coral w/ black legend	3.75 (0.9653)	N=12	3.43 (1.1339)	N=7

* 1 = not useful, 5 = extremely useful

Survey Question #4: Ranking Sample Signs Relative to Visibility

For question 4 on the post-test questionnaire (see Appendix U), drivers were shown sign color samples and photos of all four TEST DETOUR sign color combinations taken during daylight viewing conditions and 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 one, 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. Note that for this question, data from four younger subjects and one older subject were discarded because the subjects did not answer the questions correctly (e.g., skipped a number when ranking), leaving a total N of 65.

An analysis to determine if the drivers ranked the sign colors differently was significant, $F_r(3,N=65) = 38.15 > F_{tab}(\alpha=0.05,df=3) = 7.82$ (see Table 34 for rank sums). Pairwise comparisons (see Appendix Z, Table Z-7) revealed that the orange, purple, and light blue signs were ranked significantly more visible than the coral sign.

Table 34. Survey question 4 mean rankings for assessment for sign color.

Sign Colors	Rank Sum
Orange w/ black legend	140
Purple w/ yellow legend	133
Light Blue w/ black legend	162
Coral w/ black legend	215

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 (see Table 35 mean scores). The result was not significant, $F_r(3,N=2) = 4.2 < F_{tab}(\alpha=0.05,df=3) = 7.82$, indicating that younger and older drivers did not rank the visibility of each sign color in the photos differently.

Table 35. Survey question 4 mean rankings for assessment for age.

	Younger Drivers		Older Drivers	
Sign Colors	Mean (STD)	# of Obs.	Mean (STD)	# of Obs.
Orange w/ black legend	1.97 (0.8907)	N=35	2.37 (1.2452)	N=30
Purple w/ yellow legend	2.06(1.1868)	N=35	2.03 (0.8087)	N=30
Light Blue w/ black legend	2.80 (0.9641)	N=35	2.10 (1.0756)	N=30
Coral w/ black legend	3.17 (0.9848)	N=35	3.47 (0.6814)	N=30

*1 = most visible, 4 = least visible

Survey Question #5: Ranking Sample Signs Relative to Readability.

As with question 4, drivers were shown sign color samples and photos of the four TEST DETOUR sign color combinations taken during daylight conditions and asked to rank them in order of preference based on how easy they are to read (see Appendix U). Again, the most preferred sign was equated to a numerical value of one, 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. Note that for this question, data from four younger subjects and two older subjects were discarded because the subjects did not answer the questions correctly (e.g., skipped a number when ranking), leaving a total N of 64.

An analysis to determine if the drivers ranked the sign colors differently was significant, $F_r(3,N=64) = 24.08 > F_{tab}(\alpha=0.05,df=3) = 7.82$ (see Table 36 for rank sums). Pairwise comparisons (see Appendix Z, Table Z-8) revealed that the purple and light blue signs were ranked significantly easier to read than the coral signs. There were no significant differences between the orange sign and the other sign colors.

Table 36. Survey question 5 mean rankings for assessment for sign color.

Sign Colors	Rank Sum
Orange w/ black legend	168
Purple w/ yellow legend	138
Light Blue w/ black legend	136
Coral w/ black legend	198

An analysis was conducted to determine if there was a difference between rankings given by younger and older drivers (see Table 37 for mean scores). The result was not significant, $F_r(3,N=2) = 4.2 < F_{tab}(\alpha=0.05,df=3) = 7.82$, indicating that younger and older drivers did not rank the readability of each sign color in the photos differently.

Table 37. Survey question 5 mean rankings for assessment for age.

	Younger Drivers		Older Drivers	
Sign Colors	Mean (STD)	# of Obs.	Mean (STD)	# of Obs.
Orange w/ black legend	2.37 (1.0025)	N=35	2.84 (1.0984)	N=29
Purple w/ yellow legend	1.97 (1.1585)	N=35	2.40 (0.9826)	N=29
Light blue w/ black legend	2.63 (1.0596)	N=35	1.58 (0.9583)	N=29
Coral w/ black legend	3.03 (1.0142)	N=35	3.17 (0.8048)	N=29

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

Survey Question #6: Ranking Sample Signs Relative to Overall Preference.

For this question (see Appendix U), drivers were shown sign color samples and photos of the four TEST DETOUR sign color combinations taken during daylight conditions. The subjects 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 one, and the least preferred sign was equated to a numerical value of four. A Friedman two-way analysis of variance by ranks was used to analyze the data. Note that for this question, data from three older subjects were discarded because the subjects did not answer the questions correctly (e.g., skipped a number when ranking), leaving a total N of 67.

An analysis to determine if the drivers ranked the sign colors differently was significant, $F_r(3,N=67) = 35.47 > F_{tab}(\alpha=0.05,df=3) = 7.82$ (see Table 38 for rank sums). Pairwise comparisons (see Appendix Z, Table Z-9) revealed that the orange, purple, and light blue signs were ranked significantly more preferable for providing temporary directional/detour information than the coral sign.

Table 38. Survey question 6 mean rankings for assessment for sign color.

Sign Colors	Rank Sum
Orange w/ black legend	152
Purple w/ yellow legend	135
Light Blue w/ black legend	164
Coral w/ black legend	219

An analysis was also conducted to determine if there was a difference between rankings given by younger and older drivers (see Table 39 for mean scores). The result was not significant, $F_r(3,N=2) = 4.2 < F_{tab}(\alpha=0.05,df=3) = 7.82$, indicating that there was not a difference between younger and older drivers for sign preference.

Table 39. Survey question 6 mean rankings for assessment for age.

	Younger Drivers		Older Drivers	
Sign Colors	Mean (STD)	# of Obs.	Mean (STD)	# of Obs.
Orange w/ black legend	2.18 (1.0729)	N=39	2.28 (1.1705)	N=28
Purple w/ yellow legend	1.90 (1.1652)	N=39	2.27 (1.0148)	N=28
Light blue w/ black legend	2.77 (0.9857)	N=39	2.06 (1.0307)	N=28
Coral w/ black legend	3.15 (0.8747)	N=39	3.43 (0.7418)	N=28

*1 = most preferred, 4 = least preferred

DISCUSSION

The discussion that follows is presented in terms of the primary goal of this study, which was to identify the sign color combination, if any, that proved more effective than traditional orange and black detour signs for marking an alternate travel route. As mentioned previously, the ultimate measure of a traffic sign's effectiveness is how quickly and clearly the message is understood by the driver. In this study, directional information was presented to the driver informing him or her of unexpected route changes. A less conspicuous sign or a sign that was not easily read would likely result in a late reaction to a sign, or a wrong or missed turn. A sign too similar to neighboring construction or detour signs might also yield the same result.

The present study determined that there is a significant difference in driver behavior, specifically how quickly the driver was able to detect and understand the detour signs, based on the color of the signs placed along the travel path. The late reaction behaviors measured using braking data at site 20 show a trend toward a higher level of conspicuity for the black on light blue and the yellow on purple signs, with these signs resulting in fewer late braking maneuvers in order to accomplish the required turn, although no significant differences were reported. It is important to note that the site at which this data was collected was the only rural route change where an advance detour sign was not posted, and the road geometry was such that the driver would have to detect the sign quickly in order to avoid a late braking maneuver. The sign was posted at an intersection that occurred after a curve in the road. In order to make the turn indicated by the sign, the driver had to detect and read the sign immediately upon coming out of the curve, and brake for the turn. Like the other rural turn locations along the experimental route, an advance detour sign would have reduced the incidence of late braking maneuvers at this location, however, the test sign placement reflected a realistic, though not desirable, placement of this type of temporary traffic control device. Further research with a larger group of drivers is required in order to obtain a more confident and definitive interpretation of these data types.

This study also determined that there is a significant difference, based on the colors of the sign, in the amount of difficulty drivers experienced while following the directional information provided by these signs. An analysis of turn errors revealed that only the light blue and black signs resulted in significantly fewer incorrect turns than the traditional orange and black signs and tended to result in fewer incorrect turns than either the purple and black or the coral and black signs, thus indicating that the black on light blue sign is more conspicuous than the other sign colors combinations.

The results from the analyses of late braking maneuvers and turn errors should be interpreted with caution. There are several external factors which may have influenced the conspicuousness and legibility of the test signs, and thus the driver's ability to detect and interpret the signs. First, while all drivers were given explicit instructions to look for "Test Detour" signs, some drivers felt that an advance detour sign was needed to mark the beginning of the experimental route. This is a reasonable and practical suggestion since advance detour signs are usually placed prior to a route change; the existing detour employed an advance sign. Second, one must consider the sign placement at the first three sites, where signs were mounted very high above street level (3-4 m, or 10-13 ft) and were posted below existing detour and/or above other traffic control signs. Several participants noted that the signs were placed higher above street level than would normally be expected, and that they did not notice the signs posted high above the street level. Given the circumstances of the locations, no other method was available to post the signs in a way that placed them closer to a more standard 2.13 m (7 ft) above street level. Third, one must consider that the arrow icons used on the test signs were approximately one-half the size of the arrow icons used on the existing detour signs. Many drivers complained that the test arrows were too small to identify until very close to the test signs. Drivers may have quickly noticed and recognized the test signs by color, but they were unable to identify the directional information quickly and accurately due to the size of the arrow. Finally, the identification of arrow direction on test detour signs was complicated by the use of Velcro and/or bolts to attach horizontal (left or right) arrow plates to the sign face, a phenomenon that was not observed for the existing signs. Because the arrows were smaller than normal, the close proximity of Velcro strips or bolt heads tended to distorted arrow shapes. This increased the level of difficulty experienced by drivers in identifying arrow directions, especially at night when lighting varied with outside light sources and moving vehicular headlights.

Given all of the above, however, one cannot ignore the facts that no drivers demonstrated difficulty in distinguishing the light blue test signs from existing orange detour or construction zone signs, and no drivers became confused about directions or unable to distinguish the arrow directions when a route change was indicated by the light blue and black signs.

Subjective Preference and Comments

The present study determined that detour signs featuring one of two color combinations resulted in a higher level of conspicuity, under day and night conditions for younger and older drivers, than standard orange and black signs when these signs are overlaid with existing orange and black detour signs; however, driver acceptance of those signs for the prescribed function is also important. This section provides a brief discussion of the survey results and subjective comments given for each color combination tested in Study 2.

Recall that questions 1, 2, and 3 requested that the drivers rate the sign that they used while navigating the test route. Note that ratings were made without having seen the other experimental sign colors. For the assessment for sign color across the three ratings, the coral and black color combination was rated consistently low. Younger drivers who used the purple and yellow signs to navigate tended to rate those signs higher than younger drivers who used the other sign colors. Older drivers who used light blue and black signs tended to rate those signs higher than older drivers who used the other sign color combinations. The older drivers' preference for black on light blue may result from the high contrast within this sign, especially at night. This explanation seems highly likely since the nighttime drivers who used the light blue and black signs rated them consistently higher than nighttime drivers who used the other sign colors. The higher contrast effect at night may be a result of the fact that the light blue background fades to appear white when headlights reflect on the sign, resulting in a an appearance similar to that of white and black regulatory signs. This high-contrast effect may partially explain the high ratings.

The results from the first three survey questions should be interpreted with caution. There were fewer nighttime-older drivers (11) than nighttime-younger drivers (20), daytime older drivers (20), or daytime younger drivers (19), which may have impacted the results. Specifically, with more nighttime older drivers, it is suggested that the ratings for the light blue and black sign would have been stronger in the assessments for sign color since the older and nighttime drivers appear to favor this sign more. In addition, the range of mean ratings is not large. Across every mean rating for all analyses, the lowest rating was a 3.17 and the highest was a 4.67, with most ratings falling between 3.70 to 4.40. This means that the signs were generally rated approximately very visible, identifiable, and useful.

To answer questions 4, 5, and 6 on the post-test questionnaire, drivers looked at color samples of the background sign colors and pictures of the signs taken under daylight viewing conditions. They were then asked to rank the four colors in terms of visibility, readability, and overall preference from highest to lowest. Note that these questions were not analyzed by visibility condition since survey respondents could not make comparisons for daytime versus nighttime conditions.

Reviewing the results, it can be seen that the coral and black sign was consistently ranked the lowest across questions 4, 5, and 6 by both younger and older drivers. While completing the last three questions on the survey, the drivers would often comment that the coral sign looked like a faded orange sign, especially under reduced lighting conditions, which is likely the reason for the poor rankings. The younger drivers tended to favor the purple sign and they consistently ranked the black on light blue sign as third in order of preference. The older drivers tended to favor the light blue sign and ranked the orange sign as third in order of preference. However, based on the statistical results of these three questions, the only significant finding is that the coral and black sign is least preferred by both younger and older drivers.

Lastly, the general comments provided by drivers indicated that while some felt that the orange and black color combination was more appropriate for use on the temporary detour signs, many drivers supported use of a color combination other than the traditional orange and black. Although the survey results indicate that drivers thought that these signs were visible, readable, and useful for providing temporary directional information, several drivers remarked that these signs were too similar to [nearby] construction zone signs and detour signs. These drivers found that their attention was divided when attempting to process information from the various orange signs, and they experienced difficulty distinguishing the test signs from existing detour and/or construction signs. Furthermore, drivers commented on the distinctness of the color combinations tested, especially the purple with yellow legend and the light blue with black legend, when compared with the orange and black signs and other road traffic signs in use.

CONCLUSIONS

Recall that the primary goal of this study was to evaluate purple and yellow, light blue and black, and coral and black traffic signs in order to determine which, if any, would be more effective than existing orange and black signs for blazing alternate routes, especially when the route overlaps an existing detour, for younger and older drivers under day and night conditions. This evaluation of the human response was examined in terms of conspicuity and understandability of the specified color combinations with respect to driver age under daytime and nighttime conditions.

The present study indicated that two color combinations resulted in better driver performance than existing orange with black legend signs. The following conclusions were made:

1. A purple and yellow sign or a light blue sign and black sign will likely result in fewer late braking maneuvers if the road geometry has many tight curves.

2. A light blue and black sign will result in the fewest number of turn errors in both rural and urban settings.

3. An orange and black sign will result in more turn errors, especially during the day and particularly when it is overlaid with existing detour/construction zone signs.

4. A coral and black sign is least preferred by older and younger drivers when compared to the other sign colors tested in this study.

5. Younger drivers tend to have a preference for a purple and yellow sign and older drivers tend to have a preference for a light blue and black sign.

The results indicated a benefit for drivers in terms of driver performance when employing the light blue and black color combination to convey directional information under both day and night viewing conditions. The purple and yellow color combination is also highly distinctive within the normal traffic environment, although this color combination did not produce the same driving performance benefits with respect to turn errors that were demonstrated by the light blue and black test signs. The fact that these two color schemes resulted in few problems demonstrates that these alternate color schemes can reduce driver confusion when traversing detour routes where more than one alternate route is marked, increase the noticeability (or detectability) of signs indicating important route change information, and, as a result, reduce driver risk.

CHAPTER 5. SUMMARY AND FUTURE RESEARCH DIRECTIONS

SUMMARY

Based on the results of Study 1, an off-road examination of sign legibility, and related findings from previous research outlined in this report, the following conclusions can be made regarding the use of 0.610 m (24 in) by 0.72 m (30 in) signs featuring purple, light blue, coral, and brilliant yellow-green background:

1. There were several color combinations that produced better legibility results than the traditional orange and black color combination.

2. The combinations that produced the best legibility results overall included the coral and black and the white on blue portion of the red, white, and blue color combinations.

3. The color combinations that produced the best legibility results for the 100-mm letter height included the following: 1) the white on blue portion of red, white, and blue; 2) purple and yellow; 3) coral and black; and 4) light blue and black.

4. The color combinations that produced the best legibility results for the 125-mm letter height included: 1) coral and black; 2) light blue and black; 3) purple and yellow; 4) light blue and blue; and 5) brilliant yellow-green and black.

5. The color combinations that produced the best legibility distances for series C letters included the following: 1) coral and black; 2) orange and black; and 3) light blue and black.

6. The color combinations that produced the best legibility distances for series D letters included the following: 1) the red on white portion of red, white, and blue; 2) purple and yellow; 3) white on blue portion of red, white, and blue; 4) light blue and black; and 5) coral and black.

This research demonstrated that signs featuring color schemes based on the four currently unassigned highway sign colors (coral, light blue, purple, and brilliant yellow-green) can result in greater legibility distances than traditional orange and black signs. This result is important since these colors have been identified as having a potential application in traffic signing; use of these colors can help to provide motorists with specific types of information more rapidly, thus increasing available decision and reaction times, and improving driver safety.

Based on the combined results of the Study 1 and Study 2, an on-road examination of sign conspicuity and understandability, and related findings from previous research outlined in this report, the following conclusions can be made regarding traffic signs used for marking an alternate travel route, in particular detours around existing detours during incident management situations:

1. A color combination other than traditional orange and black should be used for trailblazing during incident management situations, especially when trailblazing alternate routes around existing detour/construction zones.

2. Coral signs with black legends should not be used for trailblazing around a critical incident.

3. A light blue and black sign is recommended since this sign resulted in minimal turn errors made by drivers in an overlapping detour, and the sign received generally favorable subjective ratings.

4. Despite the recommendation in 3, it is important to note that the light blue sign with black legend fades to take on the appearance of a regulatory sign when headlights or other strong lighting reflect onto it.

5. If the light blue and black sign is deemed inappropriate due to its appearance as a regulatory sign at night, consider using the purple and yellow color combination. In this study, the yellow on purple sign color combination resulted in fewer turn errors than black on orange and it was generally rated favorably by drivers, especially younger drivers.

These findings demonstrated that signs featuring color schemes other than standard highway orange and black can be more effective for trailblazing during incident management than the traditional signs. Motorists are already under increased stress when encountering anomalous traffic situations. The deployment of understandable and more conspicuous signs for trailblazing during incident management will reduce motorist confusion and, as a result, increase safety on the roadway.

LIMITATIONS OF THIS RESEARCH AND DIRECTIONS OF FUTURE RESEARCH

General

1. This study did not evaluate the use of fluorescent colors. Anecdotal evidence suggests that the use of fluorescent colors on signs improves their conspicuity.

2. The test signs in this study did not employ the same standard arrow size employed on the existing detour signs. Anecdotal evidence suggests that the use of larger, more appropriately sized arrow icons would improve the readability and interpretability of the information provided by these temporary detour, or incident management, signs.

3. A further investigation of the benefits associated with adverse weather would be beneficial. In this experiment, all data collection sessions were conducted in fair weather. Previous research has shown that different environmental effects, such as rain, dew, fog, and frost, can affect sign reflectorization effectiveness. Future research should investigate the effects of these weather phenomenon on the effectiveness of these traffic sign colors.

Study 2

1. Time did not permit recruitment of more drivers to participate. Seventy drivers participated in this study as compared to the 96 drivers planned. More drivers would have bolstered the statistical power of the analyses conducted, which may have resulted in more significant differences between groups, in particular with respect to driver performance data such as the late braking maneuvers.

2. It was difficult to recruit older nighttime drivers. Considering that the older age group is the fastest growing segment of the population, it is imperative that their needs for conspicuous and readable road signs be met. Future research should carefully consider older drivers so they do not feel that the roadways are unsafe for them.

3. The on-road portion of this research effort did not include evaluation of the brilliant yellow-green color that has been proposed for use for non-motorized crossings and incident management; this color was eliminated from further study in this research effort based on the results of Study 1. Further research should continue to investigate the effectiveness of this color for use on traffic control devices.

4. An observer effect may have been present. Given that two experimenters were in the vehicle during the drive, participants may have been exercising greater than normal caution. This caution may have led to decreased speeds and other differences in driving behavior (and some participants did admit to this afterward). Note that this effect is not unlike what drivers might experience while traversing an unfamiliar detour route or other anomalous traffic situation.

5. Participants may have had previous knowledge of the experimental route. The study was conducted in one location, one route was used, and test signs were in place for a total of one month. While participants were drawn from near and far across the county, it is possible that participants acquired previous knowledge of the test route or test signs. This increased familiarity may have affected the results found here.

REFERENCES

Abrams, W. B., and Berkow, R. (Ed.). (1990). *The Merck Manual of Geriatrics*. Rahway, NJ: Merck & Co. As cited in Pirkl, J. J. (1994*). Transgenerational Design: Products for an Aging Population*. New York, NY: Van Nostrand Reinhold.

Agaki, Y., Seo, T., and Motada, Y. (1996). A study of the influence of visual environments on the visibility of traffic signs. *Transportation Research Board, 75th Annual Meeting*. Washington, D. C.: National Research Council Transportation Research Board. As cited in Jenssen, G. D., Moen, T., Brekke, B., Augdal, A., and Sjøhaug, K. (1996). *Visual Performance of Fluorescent Retroreflective Traffic Control Devices: Part 1: Human Factors Visibility Study* (SINTEF Report No. STF22 A9606). Trondheim, Norway: SINTEF Transport Engineering.

Allen, T. M. and Straub, A. L. (1955). Sign brightness and legibility. *Highway Research Board Bulletin 127*. Washington, D. C.: National Research Council Highway Research Board.

Billmeyer, F. W. And Saltzman, M. (1966). *Principles of Color Technology*. New York, NY: Interscience Publishers.

Boynton, R. M. and Olson, C. X. (1987). Locating Basic Colors in the OSA Space. *Color Research and Application, 12*, 95-105. As cited in Collins, B. L. (1989). Color Appearance of Traffic Control Devices Under Different Illuminants. *Transportation Research Record 1247*. Washington, D. C.: National Research Council Transportation Research Board.

Carter, E. C., and Carter, R. C. (1981). Color and conspicuous. *Journal of the Optical Society of America, 71*(6), 723-729.

Case, H. W., Michael, J. L., Mount, G. E., and Brenner, R. (1952). Analysis of certain variables related to sign legibility. *Highway Research Board Bulletin 60*. Washington, D. C.: National Research Council Highway Research Board.

Chamberlain, G. J. And Chamberlain, D. G. (1980*). Colour: Its Measurement, Computation and Application.* Philadelphia, PA: Heyden & Son, Ltd.

Christ, R. E. (1975). Review and analysis of color coding research for visual displays. *Human Factors, 17*, 542-570. As cited in Collins, B. L. (1989). Color Appearance of Traffic Control Devices Under Different Illuminants. *Transportation Research Record 1247*. Washington, D. C.: National Research Council Transportation Research Board.

Chrysler, S. T., Danielson, S. M., and Kirby, V. M. (1996). Age differences in visual abilities in nighttime driving field conditions. In *Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting* (pp. 923-927). Santa Monica, CA: Human Factors Society.

Cole, B. and Hughes, P. K. (1984). A field trial of attention and search conspicuity. *Human Factors*, *26*(3), 299-313.

Cole, B. L., and Vingrys, A. J. (1985*). Are standards of colour vision in the transport industry justified?* (Report to the Australian Department of Aviation). As cited in Collins, B. L. (1989). Color appearance of traffic control devices under different illuminants. *Transportation Research Record 1247*. Washington, D. C.: National Research Council Transportation Research Board.

Collins, B. L. (1989). Color appearance of traffic control devices under different illuminants. *Transportation Research Record 1247*. Washington, D. C.: National Research Council Transportation Research Board.

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

Dewar, R. E. (1989). Traffic Signs. In *International Review of Ergonomics, 2* (pp. 65-86). New York, NY: Taylor & Francis Ltd.

Dewar, R. E. (1993). Traffic control devices, highway safety, and human factors. *Transportation Research Circular Number 414*. Washington, D. C.: National Research Council Transportation Research Board.

Dewar, R. E., Kline, D. W., and Swanson, H. A. (1994). Age differences in the comprehension of traffic sign symbols. *In Proceedings of the 73rd Annual Meeting of the Transportation Research Record.* Washington, D. C.: National Research Council Transportation Research Board.

Doughty, J. R. (1982). Traffic signs and markings. In Homburger, W. S., Keefer, L. E., and McGrath, W. R. (Ed.). *Transportation and Traffic Engineering Handbook* (Second Edition). Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Evans, D. W., and Ginsburg, A. P. (1985). Contrast sensitivity predicts age-related differences in highway-sign discriminability. *Human Factors, 27*(6), 637-642.

Forbes, T. W. (1939). A method for analysis of the effectiveness of highway signs. *Journal of Applied Psychology, 23,* 669-684.

Forbes, T. W. (Ed.). (1972). *Human factors in highway traffic safety research*. New York, NY: John Wiley and Sons, Inc.

Forbes, T. W., and Holmes, R. S. (1939). Legibility distances of highway destination signs in relation to letter height, letter width, and reflectorization. In *Proceedings of the Highway Research Board 19* (pp. 321-335). Washington, D. C.: National Research Council Highway Research Board.

Forbes, T. W., Fry, J. P., Jr., Joyce, R. P., and Pain, R. F. (1968). Letter and sign contrast, brightness, and size effects on visibility. *Highway Research Record 216*. Washington, D. C.: National Research Council Highway Research Board.

Forbes, T. W., Moskowitz, K., and Morgan, G. (1950). A comparison of lower case and capital letters for highway signs. In *Proceedings of the Highway Research Board 30* (pp. 355-373).

Gordon, D. A. (1981). The Assessment of Guide Sign Informational Load. *Human Factors*, *23*(4), 453-466.

Gordon, D. A. (1984). *Night Visibility of Overhead Guide Signs: A Review of the Literature* (Report No. FHWA/RD-84/087). Washington, D. C.: U. S. Department of Transportation Federal Highway Administration.

Green, B. F., and Anderson, L. K. (1956). Color coding in a visual search task. *Journal of Experimental Psychology, 51*, 19-24. As cited in Collins, B. L. (1989). Color Appearance of Traffic Control Devices Under Different Illuminants. *Transportation Research Record 1247*. Washington, D. C.: National Research Council Transportation Research Board.

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, NY: Van Nostrand Reinhold.

Hind, P. R., Tritt, B. H., and Hoffmann, E. B. (1976). Effects of level of illumination, strokewidth, visual angle and contrast on the legibility of numerals of various factors. In *Proceedings of the Australian Road Research Board, 8*, 46-55. As cited in Shepard, F. D. (1987). *Sign Legibility for Modified Messages* (FHWA/VA-87/R33). Charlottesville, VA: Virginia Transportation Research Council.

Kuntz, J. and Sleight, R. (1976). Legibility of numerals: The optimal ratio of height to width of stroke. *American Journal of Psychology*. As cited in Shepard, F. D. (1987). *Sign Legibility for Modified Messages* (FHWA/VA-87/R33). Charlottesville, VA: Virginia Transportation Research Council.

Jenkins, A. E. (1982). Consideration of the effects of background on sign conspicuity. *In Proceedings of the 11th AARB Conference* (pp. 182-205). Melbourne, Australia: Australian Road Research Board. As cited in Jenkins, S. E. and Cole, B. L. (1986). Daytime conspicuity of road traffic control devices. *Transportation Research Record 1093*. Washington, D. C.: National Research Council Transportation Research Board.

Jenkins, S. E. and Cole, B. L. (1986). Daytime conspicuity of road traffic control devices. *Transportation Research Record 1093*. Washington, D. C.: National Research Council Transportation Research Board.

Jenssen, G. D., Moen, T., Brekke, B., Augdal, A., and Sjøhaug, K. (1996). *Visual Performance of Fluorescent Retroreflective Traffic Control Devices: Part 1: Human Factors Visibility Study* (SINTEF Report No. STF22 A9606). Trondheim, Norway: SINTEF Transport Engineering.

Lauer, A. R. (1952). Age and sex in relation to accidents. *Highway Research Board Bulletin 60*. Washington, D. C.: National Research Council Highway Research Board. As cited in Haddon, W., Jr., Suchman, E. A., Klein, D. (1964). *Accident research: methods and approaches.* New York, NY: Harper & Row, Publishers.

Lauer, A. R. (1932). Improvements in Highway Safety. In *Proceedings of the Highway Research Board*, *12,* 389-401. As cited in Forbes, T. W. (1939). A method for analysis of the effectiveness of highway signs. *Journal of Applied Psychology. 23,* 669-684.

Lay, M. G. (1986). *Handbook of Road Technology Volume 2 Traffic and Transport*. New York, NY: Gordon and Breach Science Publishers.

Littell, R. C., Freund, R. J., and Spector, P. C. (1991). *SAS system for linear models (3rd. Ed.)*. Cary, NC: SAS Institute, Inc.

Lozano, R. D. (1980). The visibility, color and measuring requirements of road signs. *Lighting Research and Technology, 12,* 206-212. As cited in Collins, B. L. (1989). Color Appearance of Traffic Control Devices Under Different Illuminants. *Transportation Research Record 1247*. Washington, D. C.: National Research Council Transportation Research Board.

MacDonald, W. A., and Cole, B. L. (1988). Evaluating the role of color in a flight information cockpit display. *Ergonomics, 31*, 13-37. As cited in Collins, B. L. (1989). Color Appearance of Traffic Control Devices Under Different Illuminants. *Transportation Research Record 1247*. Washington, D. C.: National Research Council Transportation Research Board.

MacDonald, W. A., And Hoffman, E. R. (1991). Drivers' awareness of traffic sign information. *Ergonomics, 34*(5), 585-612.

Mace, D. (1988). Sign legibility and conspicuity. In *Transportation in an Aging Society, Vol. 2.* (Transportation Research Board Special Report #218) (pp. 270-290). Washington, D. C.: National Research Council Transportation Research Board. As cited in Dewar, R. E. (1989). Traffic Signs. In *International Review of Ergonomics, 2* (pp. 65-86). New York, NY: Taylor & Francis Ltd.

Markowitz, J., Dietrich, C. W., Lees, W. J., and Farman, M. (1968). *An investigation of the design and performance of traffic control devices* (BBN Report No. 1726). Cambridge, Mass: Bolt Beranek and Newman, Inc.

Massie, D. L., Campbell, K. L., and Williams, A. F. (1995). Traffic accident involvement rates by driver age and gender. *Accident Analysis and Prevention, 27*(1), 73-87.

Mills, F. W. (1933). The comparative visibility of standard luminous and non-luminous highway signs. *Public Roads, 14*, 109-128. As cited in Forbes, T. W. (1939). A method for analysis of the effectiveness of highway signs. *Journal of Applied Psychology*. *23,* 669-684.

Monty, R. W. (1984). Eye movements and driver performance with electronic automotive displays. Unpublished master's thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

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

Näätänen, R., and Summala, H. (1976). *Road-user behavior and traffic accidents*. Amsterdam, The Netherlands: North Holland Publishing Company.

National Institute on Aging. (1986). *Age words: a glossary on health and aging*, (NH Publication No. 86-1849). Bethesda, MD: National Institute on Aging, National Institutes of Health, Public Health Services, Department of Health and Human Services. As cited in Pirkl, J. J. (1994). *Transgenerational design: products for an aging population*. New York, NY: Van Nostrand Reinhold.

National Research Council, Transportation Research Board. (1988). *Transportation in an Aging Society: Improving Safety and Mobility for Older Persons* (Special Report #218). Washington, D. C.: Author. As cited in Dewar, R. E., Kline, D. W., and Swanson, H. A. (1994). Age differences in the comprehension of traffic sign symbols. In *Proceedings of the 73rd Annual Meeting of the Transportation Research Record*. Washington, D. C.: National Research Council Transportation Research Board.

Ogden, M. A., Womack, K. N., and Mounce, J. M. (1990). Motorist comprehension of signing applied in urban arterial work zones. *Transportation Research Record 1281*. Washington, D. C.: National Research Council Transportation Research Board.

Olson, P. L. (1988). *Minimum requirements for adequate nighttime conspicuity of highway signs* (UMTRI-88-8). Ann Arbor, Michigan: University of Michigan Transportation Research Institute.

Olson, P. L., and Bernstein, A. (1977). *Determine the luminous requirements of retroreflective highway signing* (Report No. UM-HSRI-77-6). Ann Arbor, Michigan: University of Michigan Transportation Research Institute.

Olson, P. L. and Bernstein, A. (1979). The nighttime legibility of highway signs as a function of their luminance characteristics. *Human Factors, 21*(2), 145-160.

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

Pain, R. F. (1969). Brightness and brightness ratio as factors in the attention value of highway signs. *Highway Research Record 275*. Washington, D. C.: National Research Council Highway Research Board.

Pietrucha, M. T. (1993). Development of an emergency zone sign. *Transportation Research Record 1421*. Washington, D. C.: National Research Council Transportation Research Board.

Post, D. L. (1983). *Color Contrast Metrics for Complex Images*. Unpublished doctoral dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Post, D. L. (1992). Applied color-vision research. In H. Widdel and D. L. Post (Ed.), *Color in Electronic Displays* (pp. 137-173). New York: Plenum Press.

Post, D. L., Costanza, E. B., and Lippert, T. M. (1982). Expressions of color contrast as equivalent achromatic contrast. In *Proceedings of the Human Factors Society 26th Annual Meeting* (pp. 581-585). Santa Monica, CA: Human Factors Society.

Post, D. L., Lippert, T. M., and Snyder, H. L. (1983). Quantifying color contrast. In *Proceedings of the Society of Photo-Optical Instrumentation Engineers*. As cited in Post, D. L. (1983). Color contrast metrics for complex images. Unpublished doctoral dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Richards, O. W. (1966). Vision at levels of night road illumination XII, Changes of acuity and contrast sensitivity with age. *American Journal of Optometry, 43*, 313-319. As cited in Forbes, T. W. (Ed.). (1972). *Human factors in highway traffic safety research*. New York, NY: John Wiley and Sons, Inc.

Richards, O. W. (1977). Effects of luminance and contrast on visual acuity, ages 16 to 90 years. *American Journal of Optometry and Physiological Optics, 54*, 178-184. As cited in Sturr, J. F., Kline, G. E., and Taub, H. A. (1990). Performance of young and older drivers on a static acuity test under photopic and mesopic luminance conditions. *Human Factors, 32*(1), 1-8.

Schober, H. A. W. (1967). The reduction of disability and discomfort glare in traffic. As cited in Selzer, M. L., Gikas, P. W., and Huelke, D. F. (Ed.). (1967). *The Prevention of Highway Injury*, Ann Arbor, MI: Highway Safety Research Institute, The University of Michigan. As cited in Sivak, M., and Olson, P. L. (1982). Nighttime legibility of traffic signs: conditions eliminating the effects of driver age and disability glare. *Accident Analysis and Prevention, 14*(2), 87-93.

Shepard, F. D. (1987). *Sign legibility for modified messages* (FHWA/VA-87/R33). Charlottesville, VA: Virginia Transportation Research Council.

Sivak, M., and Olson, P. L. (1982). Nighttime legibility of traffic signs: conditions eliminating the effects of driver age and disability glare. *Accident Analysis and Prevention*, *14*(2), 87-93.

Sivak, M., And Olson, P. L. (1985). Optimal and minimal luminance characteristics for retroreflective highway signs.. *Transportation Research Record 1027*. Washington, D.C.: National Research Council Transportation Research Board.

Sivak, M., Olson, P. L., and Pastalan, L. A. (1981). Effect of driver's age on nighttime legibility of highway signs. *Human Factors*, *23*(1), 59-64.

Smith, W. L., and Faulconer, J. E. (1971). The visual environment: its effect on traffic flow. *Highway Research Record 377* (pp. 131-148). Washington, D. C.: National Research Council Highway Research Board.

Sturgis, S. P. And Osgood, D. J. (1982). Effects of glare and background luminance on visual acuity and contrast sensitivity: Implications for driver night vision testing. *Human Factors*, *24*(3), 347-360.

Sturr, J. F., Kline, G. E., and Taub, H. A. (1990). Performance of young and older drivers on a static acuity test under photopic and mesopic luminance conditions. *Human Factors*, *32*(1), 1-8.

Summala, H. And Hietamäki, J. (1984). Drivers' Immediate Responses to Traffic Signs. *Ergonomics*, *27*(2), 205-216.

Summala, H., and Näätänen, R. (1974). Perception of highway traffic signs and motivation. *Journal of Safety Research*, *6*, 150-154.

Tannas, L. E., Jr. (Ed.). (1985). *Flat-panel displays and CRTs*. New York, NY: Van Nostrand Reinhold.

Uchikawa, K., And Boynton, R. M. (1987). Categorical color perception of Japanese observers: comparison with that of Americans. *Vision Research*, *27*, 1825-1833. As cited in Collins, B. L. (1989). Color Appearance of Traffic Control Devices Under Different Illuminants. *Transportation Research Record 1247*. Washington, D. C.: National Research Council Transportation Research Board.

U. S. Department of Transportation, Federal Highway Administration. (1969). *Standard Highway Color Specifications*. Washington, D. C.: Author.

U. S. Department of Transportation, Federal Highway Administration. (1983). *Traffic Control Devices Handbook*. Washington, D. C.: Author.

U. S. Department of Transportation, Federal Highway Administration. (1986). *National Personal Transportation Study, 1983-1984*. Washington, D. C.: Author. As cited in Dewar, R. E., Kline, D. W., and Swanson, H. A. (1994). Age differences in the comprehension of traffic sign symbols. In *Proceedings of the 73rd Annual Meeting of the Transportation Research Record*. Washington, D. C.: National Research Council Transportation Research Board.

U. S. Department of Transportation, Federal Highway Administration. (1988). *Manual on Uniform Traffic Control Devices for Streets and Highways 1988 Edition*. Washington, D. C.: Author.

U. S. Department of Transportation, Federal Highway Administration. (1993). *Part VI Standards and Guides for Traffic Controls for Street and Highway Construction, Maintenance, Utility, and Incident Management Operations (Part VI of the Manual on Uniform Traffic Control Devices, Revision 3)*. Washington, D. C.: Author.

U. S. Department of Transportation, Federal Highway Administration, Office of Traffic Operations. (1982). *Metric Edition: Standard Alphabets for Highway Signs and Pavement Markings*. Washington, D. C.: Author.

Van Norren, D. (1981). *Informatiedragers langs de weg: een overzicht van zichtbaarheidsproblemen* (Report No. 25). Soesterberg (NL): Institute of Perception (TNO). As cited in Spijkers, W. (1991). The recognition of traffic signs under 'natural' conditions. In Gale, A. G., Brown, I. D., Haslegrave, C. M., Moorhead, I., and Taylor, S. P. (Eds.). *Vision in Vehicles - III* (pp. 317-323). Amsterdam, The Netherlands: Elsevier Science Publishers B. V.

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., and Lincoln, J. E. (Ed.). (1986). *Engineering Data Compendium, Human Perception and Performance*. Wright-Patterson Air Force Base, Ohio: Harry G. Armstrong Aerospace Medical Research Laboratory.

Wierwille, W. W., and Gutman. (1978). Comparison of primary and secondary task measurements as a function of simulated vehicle dynamics and driving conditions. *Human Factors*, *20*, 233-244.

Youngblood, W. P. and Woltman, H. L. (1971). A brightness inventory of contemporary signing materials for guide signs. *Highway Research Record 377*. Washington, D. C.: National Research Council Highway Research Board.

Zwahlen, H. T., Sunkara, M., and Schnell, T. (1995). Review of legibility relationships within the context of textual information presentation. *Transportation Research Record 1485*. Washington, D. C.: National Research Council Transportation Research Board.

APPENDICES

APPENDIX A. PARTICIPANT INFORMATION FOR STUDY 1

Subject #	Age	Gender	Acuity	Corrective Lenses?	Color Vision
1	18	F	20/17	no	normal
2	20	M	20/15	no	normal
3	22	F	20/13	no	normal
4 omitted	24	F	20/25	contact lenses, not normal prescription	normal
5	22	M	20/15	no	normal
6	23	F	20/13	no	normal
7	70	M	20/25 blind in left eye	corrective lenses	mild color deficiency (not categorized by testing materials)
8	75	F	20/40	corrective lenses	normal
9	75	M	20/18	corrective lenses, bifocals	normal
10	70	F	20/25	corrective lenses, bifocals	normal
11	67	M	20/17	corrective lenses, bifocals	normal
12	74	F	20/15	corrective lenses	normal
13	42	M	20/13	no	red-green deficient
14	23	M	20/17	corrective lenses, contacts	mild red-green deficiency
15	23	M	20/20	corrective lenses	red-green deficiency
16	28	M	20/15	corrective lenses	red-green deficiency

APPENDIX B. TEST SIGN SPECIFICATIONS FOR STUDY 1

Sign #	Back-ground	Legend	1st Line Legend	1st Line Letter Height (mm)	1st Line Letter Series	2nd Line Legend	2nd Line Letter Height (mm)	2nd Line Letter Series
1	White	Red	EMERGENCY	100	D	-	-	-
1	Blue	White	-	-	-	DETOUR	100	D
2	Orange	Black	YOUNG MEN	100	C	TROUPE	125	C
3	Orange	Black	METROBUS	100	D	TOURED	125	D
4	White	Red	ME ENERGY	100	C	-	-	-
4	Blue	White	-	-	-	READY	100	D
5	White	Red	DOCUMENT	100	C	-	-	-
5	Blue	White	-	-	-	VOTED	100	C
6	Coral	Black	TEMPORARY	100	C	ROUTES	125	C
7	Coral	Black	FOR GREEN	100	D	TOWERS	125	D
8	Coral	Blue	MY PERCENT	100	C	REACTS	125	C
9	Coral	Blue	NOVEMBER	100	D	DROVE	125	D
10	Coral	White	LEGENDARY	100	C	TRULY	125	C
11	Coral	White	A MOTOR	100	D	DEPART	125	D
12	Light Blue	Black	ENTER NOW	100	C	YONDER	125	C
13	Light Blue	Black	REMOTELY	100	D	OUTER	125	D
14	Light Blue	Blue	WORKER GO	100	C	URGENT	125	C
15	Light Blue	Blue	PAYMENTS	100	D	DEVOTE	125	D

Test Sign Specifications for Study 1 (continued)

Sign #	Back-ground	Legend	1st Line Legend	1st Line Letter Height (mm)	1st Line Letter Series	2nd Line Legend	2nd Line Letter Height (mm)	2nd Line Letter Series
16	Light Blue	Yellow	MY GRADES	100	C	RACKET	125	C
17	Light Blue	Yellow	MODERN	100	D	POCKET	125	D
18	Purple	Black	ENDMARKER	100	C	COUNTS	125	C
19	Purple	Black	RED GLOW	100	D	DOCTOR	125	D
20	Purple	White	FARM GAME	100	C	GROUND	125	C
21	Purple	White	WED THRU	100	D	TRUDGE	125	D
22	Purple	Yellow	GAS METER	100	C	STORED	125	C
23	Purple	Yellow	WELCOME	100	D	DO RUN	125	D
24	Brilliant Yellow-Green	Black	GOT EMPTY	100	C	BATONS	125	C
25	Brilliant Yellow-Green	Black	DECEMBER	100	D	ROUNDS	125	D
26	Purple	Brilliant Yellow-Green	CAMPER ON	100	C	UNDOCK	125	C
27	Purple	Brilliant Yellow-Green	MONDAY	100	D	COURSE	125	D

APPENDIX C. SIGN COLORS IN CIE NOTATION

Table C-1. Sign Colors in CIE Notation (from U. S. Department of Transportation, 1969)

Color	CIE Y (%)	CIE x	CIE y
Black	9.43	0.3101	0.3163
Blue	6.56	0.1780	0.1833
Light Blue	43.06	0.2410	0.2854
Orange	24.58	0.5609	0.3950
Purple	12.00	0.3056	0.2060
Red	9.00	0.6003	0.3146
White	78.66	0.3101	0.3163
Yellow	50.68	0.5007	0.4555
Brilliant Yellow-Green	43.06	0.3461	0.4950
*Coral	49.52	0.3943	0.3251

* The FHWA-specified coral ink is Y%=51.08, x=0.3815, y=0.3169

Table C-2. Actual Ink Sample Colors in CIE Notation as measured under Simulated Daylight Conditions (samples made of Scotchlite ™ Type III High Intensity grade sheeting material; final measurement).

Color	CIE Y (%)	CIE x	CIE y
Black	2.34	0.342	0.348
Blue	7.76	0.154	0.138
Brown	11.60	0.506	0.390
Coral	54.30	0.425	0.363
Green	17.40	0.180	0.424
Light Blue	56.90	0.280	0.336
Orange	52.40	0.564	0.405
Purple	23.00	0.338	0.238
Red	14.80	0.625	0.335
White	92.50	0.347	0.359
Yellow	63.60	0.525	0.463

Table C-3. Actual Sign Colors in CIE Notation as Measured under Simulated Daylight Conditions (signs made of Scotchlite ™ Diamond Grade Reflective sheeting material; final measurement).

Color	CIE Y (%)	CIE x	CIE y
Black	2.90	0.356	0.350
Blue	7.04	0.165	0.123
Blue letters silk-screened over Light Blue	5.44	0.155	0.109
Coral	49.20	0.509	0.360
Blue letters silk-screened over Coral	2.86	0.198	0.147
Light Blue	43.00	0.241	0.311
Orange	38.20	0.594	0.386
Purple	12.70	0.350	0.215
Red	14.80	0.625	0.335
White	91.10	0.346	0.352
Yellow	67.60	0.516	0.467
Brilliant Yellow-Green	54.90	0.311	0.507

APPENDIX D. SPECIFICATIONS OF TEST SIGNS FOR STUDY 1

There was a total of 27 test signs. Each sign had a unique color, contrast, stroke width, and word combination. These unique combinations are specified in Appendix B. The development of these sign specifications is described below.

Sign Size

The standard Emergency Detour sign currently used is 0.609 meters (m) (24 inches) tall by 0.762 m (30 inches) wide. As such, the test signs were the same dimensions. An exception was a red, white, and blue Emergency Detour test sign which was 0.609 m (24 in) tall by 0.914 m (36 in) wide. This larger size was necessary to accommodate the use of series D letters for the upper legend, "Emergency," if the standard distance between letters was not to be compromised.

Sign Materials

The colored inks, Scotchlite™ Transparent Process Color by 3M, were applied to aluminum sheeting via the 3M Company's Scotchlite™ Diamond Grade Reflective sheeting material. The diamond grade sheeting material, which can be distinguished by the diamond-shaped lattice separating the sheeting layers, reflects back to the driver a maximum amount of light from vehicle headlights at a wide angle. The benefit of using diamond grade sheeting is two-fold: 1) it improves the conspicuity of the sign for both day and night conditions, and 2) it improves the conspicuity of signs that are slightly off angle, which is often the case in realistic work situations in which the worker's must rush to get the emergency signs in place.

The background colors for all of the test signs were fabricated by traditional silk screening. The legends and borders were applied to the test signs in one of several ways, depending on the color. All black legends and borders were applied using non-reflective black tape. All highway yellow legends and borders were applied using yellow-colored Scotchlite ™ Diamond Grade Reflective sheeting tape. White, blue, and brilliant yellow-green legends and borders were fabricated by traditional silk screening. Finally, the red, white, and blue signs featured red letters made from red Scotchlite™ Type III High Intensity Grade sheeting tape, which is distinguished by a hexagonal lattice or "honeycomb" appearance.

Line Legends

The *1977 Metric Edition Standard Alphabets for Highway Signs and Pavement Markings* specifies the series of letter to be used for road signs. The letter series dictates the letter stroke width, stroke width-to-height ratio, and the distance between letters for each letter height used. For the standard emergency detour sign, the first line legend, "EMERGENCY," is composed of 10.0 centimeter (cm), or 4 in, series C letters. The standard second line legend, "DETOUR," is composed of 12.7 cm, or 5 in, series D letters. The values for letter heights, stroke widths, and stroke width ratios for series C and D as used in this study are shown in the table below.

Letter series, heights, and stroke width data.

Letter Series	Letter Height	Stroke Width (mm)	Stroke Width Ratio
C	100 mm (4 inches)	14	0.14
C	125 mm (5 inches)	18	0.14
D	100 mm (4 inches)	16	0.16
D	125 mm (5 inches)	20	0.16

The data in Table 2 show that the stroke width values range from 14 mm to 20 mm, depending on the letter series and letter height. The stroke width ratio values of interest include two levels, 0.14 and 0.16. The usable letter stroke width values are limited to 0.14 and 0.16 due to the following: 1) the fact that use of series B letters is restricted by the MUTCD to signs where limited breadth and stroke widths are required (U. S. Department of Transportation, 1988), and 2) the fact that use of the larger series E and F letters would greatly exceed the sign size desired.

First Line Legend

The first line legend letter series used in this study was series C or D. The letter height for the top row of characters (i.e., EMERGENCY in the standard sign) was the current standard of 10.0 cm (4 in) or the tested height of 12.7 cm (5 in). The word or words chosen for the first line legend were intended to have the same geometric shapes as the all-capitalized word "EMERGENCY." The text, letter series, and letter height for the first line of legend to appear on each sign is specified for each sign number in Appendix B.

Although the distance between letters is standardized for the letter height, the distance between letters was often reduced for this study (see Appendix E). Due to the constraints of the sign size, 24 in by 30 in, the distance between letters had to be increased or decreased as necessary to fit the desired legend text. In some cases, no reduction in letter spacing was required; however, most legends required that the letter spacing be reduced as much as 50-70% or more. There were also several instances in which spacing was slightly increased.

The line length varied depending on the letters and spacing. For the series C letters, the average line length was 625 mm (range of 559 mm to 664 mm). This is in comparison to 648 mm for the standard black on orange "EMERGENCY" legend. For the series D letters, the average line length was 596 mm (range of 531 mm to 665 mm). This was in comparison to 798 mm for the red, white, and blue "EMERGENCY" legend.

Second Line Legend

The second line legend was either series C or series D. The letter height for the bottom row of characters was either the current standard of 12.7 cm (5 in) or the tested height of 10.0 cm

(4 in). The word or words chosen for the first line legend were intended to have the same geometric shapes as the all-capitalized word "DETOUR." The text, letter series, and letter height for the first line of legend to appear on each sign are specified for each sign number in Appendix B.

Again, the distance between letters was often reduced (see Appendix E) even though the second line legend fit the sign size. Although this was not specified for the test sign designs, it is suspected that the sign shop employees who fabricated the signs felt that the signs looked better if the spacing was more consistent. The legends were reduced as much as 20-50% or more. There were also several instances in which spacing was slightly increased.

Once again, the line length varied depending on the letters and spacing. For the series C letters, the average line length was 514 mm (range of 350 mm to 551 mm). For the series D letters, the average line length was 579 mm (range of 428 mm to 666 mm). This was in comparison to 628 mm for the standard black on orange "EMERGENCY" legend, and 510 mm for the red, white, and blue "EMERGENCY" legend.

Line Spacing

While line spacing was not a factor of interest in this research, differences in the fabrication of the many test signs introduced differences in the spacing between lines of text. The standard orange and black Emergency Detour sign featured 64 mm between the lines of text. The red, white, and blue Emergency Detour sign featured 135 mm between the lines of text, while the other red, white, and blue test signs featured approximately 94 mm of space between lines of text. The line spacing for the remainder of test signs ranged from 51 mm to 67 mm, with an average of 55 mm.

Color

The background sign colors of interest included brilliant yellow-green, coral, light blue, and purple. Also, the standard black on orange emergency sign and a red, white, and blue sign were evaluated. In total, 13 color combinations, which represented the color pairings that resulted in the greatest luminance and/or color contrast values obtained in a preliminary study, were evaluated. The combinations, background and legend, are as follows: 1) orange and black; 2) coral and black; 3) coral and blue; 4) coral and white; 5) light blue and black; 6) light blue and blue; 7) light blue and yellow; 8) purple and black; 9) purple and white; 10) purple and yellow; 11) brilliant yellow-green and black; 12) purple and brilliant yellow-green; and 13) white with red letters and blue with white letters on the same sign. This last color combination represents the red, white, and blue sign currently under consideration for emergency detour routing in Northern Virginia. The color combinations were chosen based on analyses of luminance contrast and color contrast.

The correct Commission International d'Eclairge (CIE) Notations for the background and legend colors are provided in Appendix C as specified in the *Standard Highway Color*

Specifications (U. S. Department of Transportation, 1969). Although close in notation, the coral color specified is not the same as that in the *Standard Highway Color Specifications* (U. S. Department of Transportation, 1969). The reason for the discrepancy is that the specified coral ink was not available at the time of testing. Therefore, the coral-colored ink specified in Appendix C was used for the duration of this experiment.

Contrasts

The background and legend color combinations used in this study were chosen based on analyses of luminance contrast and color contrast. The first contrast type, luminance contrast (also called brightness contrast), is a function of the difference in luminance of the sign legend and background, and is a significant factor for legibility at night. These luminance values are a function of the geometric conditions of lighting and observation. In order to determine approximate luminance contrast values, it was necessary to reproduce the expected range of lighting conditions in the laboratory and to obtain luminance measurements. The lighting conditions varied with environmental lighting (daylight and other external lighting) and the intensity of vehicle headlights. The second contrast type considered is color contrast, which is related to the perception of color differences and is very important during the day. For the purposes of this study, the 1976 CIE $L^*u^*v^*$ distance between visible color stimuli was employed to determine color distances and the corresponding best estimate of perceived color contrasts (Post, Costanza, and Lippert, 1982) (Refer to Appendix F for a description of the CIE system and the 1976 CIE $L^*u^*v^*$ distance).

The actual luminance values, calculated luminance contrast values, and contrast ratio values obtained for development of the sign specifications are shown in Appendices G and H for three environmental conditions. These conditions were simulated in the laboratory and include average day light, nighttime with an average low beam headlight at 30 meters (m), and nighttime with an average low beam headlight at 90 m. A Macbeth® Spectralight® II lighting booth was used to produce an average day lighting condition of 565 lux. A darkened room with a 150-watt reflector incandescent light bulb set approximately 3 meters from the color sample was used to provide equivalent average low beam lighting of 10 kilocandela (kcd) at 30 meters (approximately 140 lux) and 90 meters (approximately 15.5 lux) as specified by Lay (1986). Luminance measurements were obtained for all color samples (i.e., paint chips coated with reflective sheeting) under all three conditions using a Minolta CS-100 Chroma Meter and a Minolta T-1 Illuminance Meter. The percent contrast was then calculated by dividing the absolute value of the difference in background and legend luminances by the larger luminance value. In Appendices F and G, the values shown as bold in each column are the two highest luminance contrasts for each background color. Note that values are not given for brilliant yellow-green and black because color samples were not available at the time of measurement.

The estimates of perceived color contrasts were calculated using the CIE color notations as specified in the *Standard Highway Color Specifications* (U. S. Department of Transportation, 1969). The color contrast values are shown in Appendix I for all potential sign color combinations featuring coral, light blue, or purple as the background color, as well as for the orange and black color combination, the red, white, and blue color combination, and the brilliant yellow-green and black color combination. The values were calculated using the 1976 CIE $L^*u^*v^*$ distance between color stimuli, which Post et al. (1982) concluded was the "best available metric of suprathreshold color distance." The greater the distance, $dL^*u^*v^*$, between two visible colors, the greater the perceived color contrast between those colors. The values shown as bold in each column are the two highest color contrasts for each background color.

Sign Border

With few exceptions, the MUTCD requires all signs to have a border of the same color as the legend. The border is used to emphasize the shape geometry of the sign, particularly in darkened conditions where it becomes difficult to recognize the sign. All inset borders are approximately 9.5 mm (0.375 in) from the edge of the sign panel, except for the red, white, and blue test signs which feature an upper border inset 19.1 mm (0.750 in). All other borders are flush to the edge of the sign panel. The dimensions of the borders for the test signs were as follows:

- The red, white, and blue Emergency Detour test sign features a black inset border on the top of 12.7 mm (0.500 in) width, and a white flush border on the bottom also of 12.7 mm (0.500 in) width.

- All other inset borders are 16 mm (0.625 in) wide.

- All other borders flush with the sign edges are 19.1 mm (0.750 in). This is similar to the current standard Emergency Detour sign which features an inset border with a width of 19.1 mm (0.750 in).

Refer to Appendix E for detailed border data for all test signs.

The amount of horizontal space located within the sign border varies depending on border thickness and whether the border was inset or flush to the edge of the sign panel. The horizontal distance inside the inset border averaged 706 mm (range 688 mm to 710 mm). This was compared with 702 mm for the standard black on orange emergency detour sign, and 865 mm for the red, white, and blue emergency detour sign. The horizontal distance inside the flush border averaged 723 mm (range 722 mm to 723 mm). This was in comparison to 886 mm for the red, white, and blue emergency detour sign.

APPENDIX E. DESCRIPTION OF TEST SIGN DIMENSIONS

Table E-1. Description of test sign legends, lengths, and letter spacing.

Spec.* Sign #	Colors†	Legend Text Lines 1 & 2	Legend Length (mm) 1st Line	Legend Length (mm) 2nd Line	Type - SilkScrn or Tape (S/T)	Letter Spacing 1st Line	Letter Spacing 2nd Line	Line Spacing (mm)
	o/blk	*EMERGENCY DETOUR*	648	628	T	normal	normal	64
1	r/w	*EMERGENCY*	798		T	normal		135
1	blu/wh	*DETOUR*		510	S		normal	
2	o/blk	YOUNG MEN TROUPE	661	533	T	reduce up to 20%	reduce up to 20%	54
3	o/blk	METROBUS TOURED	622	640	T	reduce up to 50+%	normal	56
4	r/w	ME ENERGY	641		T	normal		94
4	blu/wh	READY		428	S		reduce up to 17-60%	
5	r/w	DOCUMENT	574		T	reduce up to 20+%		93
5	blu/wh	VOTED		350	S		normal	
6	c/blk	TEMPORARY ROUTES	647	540	T	reduce up to 30+%	**reduce up to 10%	53
7	c/blk	FOR GREEN TOWERS	665	666	T	reduce up to 50+%	normal	51
8	c/blu	MY PERCENT REACTS	642	533	S	reduce up to 50+%	**reduce up to 20%	56
9	c/blu	NOVEMBER DROVE	629	535	S	reduce up to 50+%	**reduce up to 20%	56
10	c/wh	LEGENDARY TRULY	559	420	S	reduce up to 12%	**reduce up to 10%	62
11	c/wh	A MOTOR DEPART	557	558	S	reduce up to 50+%	reduce up to 50+%	53
12	Lblu/blk	ENTER NOW YONDER	664	551	T	normal	**reduce up to 20%	52

*Identification numbers correspond with those listed in Appendix B.
**Most letter spacing is normal.
†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Table E-1. Description of test sign legends, lengths, and letter spacing (continued).

Spec.* Sign #	Colors†	Legend Text Lines 1 & 2	Legend Length (mm) 1st Line	Legend Length (mm) 2nd Line	Type - SilkScrn or Tape (S/T)	Letter Spacing 1st Line	Letter Spacing 2nd Line	Line Spacing (mm)
13	Lblu/blk	REMOTELY OUTER	641	532	T	reduce up to 20-100+%	normal	51
14	Lblu/blu	WORKER GO URGENT	591	537	S	reduce up to 70+%	normal	56
15	Lblu/blu	PAYMENTS DEVOTE	604	628	S	reduce up to 50-100+%	**reduce up to 20%	56
16	Lblu/y	MY GRADES RACKET	594	540	T	reduce up to 50-60+%	normal (big)	51
17	Lblu/y	MODERN POCKET	534	560	T	normal	reduce up to 50+%	54
18	p/blk	END MARKER COUNTS	593	541	T	reduce up to 50+%	**reduce up to 15%	58
19	p/blk	RED GLOW DOCTOR	614	652	T	reduce up to 50-65+%	normal (big)	58
20	p/wh	FARM GAME GROUND	657	533	S	reduce up to 65+%	reduce up to 20%	67
21	p/wh	WED THRU TRUDGE	582	557	S	reduce up to 66+%	reduce up to 50+%	53
22	p/y	GAS METER STORED	605	530	T	reduce up to 50+%	**reduce up to 20%	55
23	p/y	WELCOME DO RUN	559	560	T	reduce up to 25-65+%	reduce up to 38-50+%	53
24	yg/blk	GOT EMPTY BATONS	661	526	T	normal	**reduce up to 12%	51
25	yg/blk	DECEMBER ROUNDS	615	654	T	reduce up to 50+%	normal	56
26	p/yg	CAMPER ON UNDOCK	658	545	S	normal	normal	55
27	p/yg	MONDAY COURSE	531	558	S	normal w/ overlap	reduce up to 60+%	61

*Identification numbers correspond with those listed in Appendix B.

**Most letter spacing is normal.

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Table E-2. Description of test sign borders.

Spec.* Sign #	Colors†	Legend Lines 1/2	Border Thickness (in)	Border Inset or Flush (I/F)	Inset Distance (in)	Space Inside Border (mm)
	o/blk	*EMERGENCY DETOUR*	0.750	I	0.375	702
1	r/w	*EMERGENCY*	0.500	I	0.375	865
1	blu/wh	*DETOUR*	0.500	F		886
2	o/blk	YOUNG MEN TROUPE	0.625	I	0.375	710
3	o/blk	METROBUS TOURED	0.625	I	0.375	707
4	r/w	ME ENERGY	0.625	I	0.750	693
4	blu/wh	READY	0.750	F		724
5	r/w	DOCUMENT	0.625	I	0.750	688
5	blu/wh	VOTED	0.750	F		722
6	c/blk	TEMPORARY ROUTES	0.625	I	0.375	709
7	c/blk	FOR GREEN TOWERS	0.625	I	0.375	708
8	c/blu	MY PERCENT REACTS	0.625	I	0.375	708
9	c/blu	NOVEMBER DROVE	0.625	I	0.375	707
10	c/wh	LEGENDARY TRULY	0.750	F		724
11	c/wh	A MOTOR DEPART	0.750	F		723
12	Lblu/blk	ENTER NOW YONDER	0.625	I	0.375	708
13	Lblu/blk	REMOTELY OUTER	0.625	I	0.375	708
14	Lblu/blu	WORKER GO URGENT	0.625	I	0.375	709
15	Lblu/blu	PAYMENTS DEVOTE	0.625	I	0.375	709
16	Lblu/y	MY GRADES RACKET	0.625	I	0.375	707
17	Lblu/y	MODERN POCKET	0.625	I	0.375	703
18	p/blk	END MARKER COUNTS	0.625	I	0.375	706
19	p/blk	RED GLOW DOCTOR	0.625	I	0.375	708
20	p/wh	FARM GAME GROUND	0.750	F		723
21	p/wh	WED THRU TRUDGE	0.750	F		723
22	p/y	GAS METER STORED	0.625	I	0.375	709
23	p/y	WELCOME DO RUN	0.625	I	0.375	706
24	yg/blk	GOT EMPTY BATONS	0.625	I	0.375	709
25	yg/blk	DECEMBER ROUNDS	0.625	I	0.375	707
26	p/yg	CAMPER ON UNDOCK	0.625	I	0.375	704
27	p/yg	MONDAY COURSE	0.625	I	0.375	704

*Identification numbers correspond with those listed in Appendix B.
†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

APPENDIX F. THE CIE SYSTEM AND THE 1976 L*U*V* DISTANCE

The colors under examination in this study are defined in terms of the standard Commission International d'Eclairge (CIE) color measurement system. This system provides a means by which visible colors can be specified, measured, and reproduced, and is based upon three tristimulus values or artificial primaries, X, Y, and Z, which are approximately equal to red, green, and blue, respectively. Visible (i.e., real) colors can be defined in terms of chromaticity coordinates derived from the proportions of these primaries. These coordinates are defined according to the following equations:

$x = X / (X+Y+Z)$; $y = Y / (X+Y+Z)$; and $z = Z / (X+Y+Z)$

The notation used to specify the test colors consists of three coordinates--x, y, and Y. The sum of the chromaticity coordinates is 1, thus only two of the three chromaticity coordinates, x and y, are necessary to describe or characterize a color. The third coordinate, the Y tristimulus value, is the luminance value and it corresponds to the intensity of the matching light, which is equal to the luminous transmittance or luminous reflectance of the object (Billmeyer and Saltzman, 1966; Tannas, 1985).

The 1976 CIE L*u*v* uniform color space is a three-dimensional space which provides one achromatic and two chromatic axes, all orthogonal with one another. It combines 1976 CIE metric lightness, L*, with one of the two formulations of 1976 CIE metric chromaticity, u* and v*. L* was developed independently of the metric chromaticities and is intended to represent the approximate lightness of reflecting objects, or the extent to which that object appears to reflect light (Post, 1983). The 1976 CIE L*u*v* distance between stimuli, i.e., color difference, is defined as follows (Tannas, 1985):

$$dL^*u^*v^* = (dL^{*2} + du^{*2} + dv^{*2})^{1/2}$$

where $dL^*u^*v^*$=distance between colors,
dL^*=distance between the colors' L* values,
du^*, dv^* = distances between the colors' u* and v* values, respectively,
$L^*=25(100Y/Y_0)^{1/3} - 16$,
$u^*=13L^*(u')$, $v^*=13L^*(v')$,
$u'=2x(6y-x+1.5)$, $v'=3y(6y-x+1.5)$, and
Y_0=Y value of the illuminant, $1<Y_0<100$.

For convenience, the value of Y_0 is assumed to equal 100, i. e., perfect diffusing reflector. According to Post (1983), "it can be shown that the only practical consequence is that the resulting values for L* cannot be compared directly with values obtained using some other constant because the units will differ." Refer to Post (1983) for details of the derivation of this color space.

APPENDIX G. LUMINANCE AND CONTRAST DATA FOR STUDY 1

Table G-1. Actual Luminance Measurements and Calculated Luminance Contrast for Simulated Daylight Condition Using Original Ink Color Samples (made with Scotchlite™ Type III High Intensity grade sheeting materials).

Color	**Luminance Measurement (cd/m^2)**	**Luminance Contrast w/ Coral (%)***	**Luminance Contrast w/ Light Blue (%)***	**Luminance Contrast w/ Purple (%)***
Black	2.34	**96**	**96**	**90**
Blue	7.76	**86**	**86**	66
Brown	11.60	79	80	50
Red	14.80	73	74	36
Green	17.40	68	69	24
Orange	52.40	3	8	56
Yellow	63.60	15	11	64
White	92.50	41	38	**75**
Coral	54.30	-	5	58
Light Blue	56.90	5	-	60
Purple	23.00	58	60	-
Color Combination**	**Luminance Contrast (%)***			
Orange & Black	96			
Red & White	84			
Blue & White	92			
White & Black	97			

*A larger number denotes a greater contrast.
**A luminance contrast value is not shown for brilliant yellow-green and black because color samples were not available at the time of measurement.

Table G-2. Actual Luminance Measurements and Calculated Luminance Contrast for Simulated Daylight Condition Using Actual Test Signs (made with Scotchlite ™ Diamond Grade Reflective sheeting materials).

Color	**Luminance Measurement (cd/m^2)**	**Luminance Contrast w/ Coral (%)***	**Luminance Contrast w/ Light Blue (%)***	**Luminance Contrast w/ Purple (%)***
Black	2.90	**94**	**93**	77
Blue	7.04	86	84	45
Red	14.80	70	66	14
Orange	38.20	22	11	67
Yellow	67.60	27	36	**81**
White	91.10	46	53	**86**
Coral	49.20	-	13	74
Light Blue	43.00	13	-	70
Purple	12.70	74	70	-
Brilliant Yellow-Green	54.90			77
Blue letters silk-screened over Light Blue	5.44		**87**	
Blue Letters silk-screened over Coral	2.86	**94**		

Color Combination**	**Luminance Contrast (%)***
Orange & Black	92
Red & White	84
Blue & White	92
White & Black	97
Brilliant Yellow-Green & Black	95

*A larger number denotes a greater contrast.

Table G-3. Actual Luminance Measurements and Calculated Luminance Contrast for Simulated Night Condition with Low-Beam Headlight at 30 Meters Using Original Ink Color Samples.

Color	**Luminance Measurement (cd/m^2)**	**Luminance Contrast w/ Coral (%)***	**Luminance Contrast w/ Light Blue (%)***	**Luminance Contrast w/ Purple (%)***
Black	5.48	**97**	**99**	**98**
Blue	56.00	68	**90**	80
Brown	150.00	14	74	48
Red	129.00	26	78	55
Green	282.00	38	51	2
Orange	386.00	55	33	26
Yellow	623.00	72	8	54
White	1950.00	**91**	70	**85**
Coral	174.00	-	70	39
Light Blue	576.00	70	-	50
Purple	287.00	39	50	-

Color Combination**	**Luminance Contrast (%)***
Orange & Black	99
Red & White	86
Blue & White	97
White & Black	100

*A larger number denotes a greater contrast.
**A luminance contrast value is not shown for brilliant yellow-green and black because color samples were not available at the time of measurement.

Table G-4. Actual Luminance Measurements and Calculated Luminance Contrast for Simulated Night Condition with Low-Beam Headlight at 90 Meters Using Original Ink Color Samples.

Color	Luminance Measurement (cd/m^2)	Luminance Contrast w/ Coral (%)*	Luminance Contrast w/ Light Blue (%)*	Luminance Contrast w/ Purple (%)*
Black	0.28	**99**	**100**	**99**
Blue	5.10	75	**91**	**84**
Brown	9.12	55	84	71
Red	12.50	38	78	60
Green	28.90	30	50	7
Orange	40.40	50	30	23
Yellow	73.90	73	22	58
White	94.20	**78**	39	67
Coral	20.30	-	65	35
Light Blue	57.90	65	-	46
Purple	31.10	35	46	-

Color Combination**	Luminance Contrast (%)*
Orange & Black	99
Red & White	69
Blue & White	95
White & Black	100

*A larger number denotes a greater contrast.

**A luminance contrast value is not shown for brilliant yellow-green and black because color samples were not available at the time of measurement.

APPENDIX H. CONTRAST RATIOS

Table H-1. Contrast Ratios (Cr = Lmax/Lmin) Based on Standard Highway Colors' CIE Notations.

Color	**Luminance Measurement (cd/m^2)**	**Contrast Ratio w/ Coral***	**Contrast Ratio w/ Light Blue***	**Contrast Ratio w/ Purple***
Black	9.43	5.4	4.6	1.3
Blue	6.56	**7.8**	6.6	1.8
Brown	5.52	**9.2**	**7.8**	2.2
Red	9.00	5.7	4.8	1.3
Green	6.56	**7.8**	**6.6**	1.8
Orange	24.58	2.1	1.8	2.0
Yellow	50.68	1.0	1.2	4.2
White	78.66	1.5	1.8	**6.6**
Coral	51.08	-	1.2	**4.3**
Light Blue	43.06	1.2	-	1.8
Purple	12.00	4.3	3.6	-
Brilliant Yellow-Green	43.06	1.2	1.0	3.6

Color Combination**	**Contrast Ratio***
Orange & Black	2.6
Red & White	8.7
Blue & White	12.0
White & Black	8.3
Brilliant Yellow-Green & Black	3.6

*A larger number denotes a greater contrast.

Table H-2. Contrast Ratios Based on Original Ink Sample Colors (as measured under simulated daylight conditions).

Color	**Luminance Measurement (cd/m^2)**	**Contrast Ratio w/ Coral***	**Contrast Ratio w/ Light Blue***	**Contrast Ratio w/ Purple***
Black	2.34	**23.2**	**24.3**	**9.8**
Blue	7.76	**7.0**	**7.3**	3.0
Brown	11.60	4.7	4.9	2.0
Red	14.80	3.7	3.8	1.6
Green	17.40	3.1	3.3	0.8
Orange	52.40	1.0	1.1	2.3
Yellow	63.60	0.9	0.9	2.8
White	92.50	1.7	1.6	**4.0**
Coral	54.30	-	1.0	2.4
Light Blue	56.90	1.0	-	2.4
Purple	23.00	2.4	2.5	-

Color Combination**	**Contrast Ratio***
Orange & Black	22.4
Red & White	6.3
Blue & White	11.9
White & Black	39.5

*A larger number denotes a greater contrast.
**A contrast ratio value is not shown for brilliant yellow-green and black because color samples were not available at the time of measurement.

Table H-3. Contrast Ratios Based on Actual Test Sign Colors (as measured under simulated daylight conditions).

Color	Luminance Measurement (cd/m^2)	Contrast Ratio w/ Coral*	Contrast Ratio w/ Light Blue*	Contrast Ratio w/ Purple*
Black	2.90	**17.0**	**14.8**	**4.4**
Blue	7.04	**7.0**	**6.1**	1.8
Red	14.80	3.3	2.9	0.9
Orange	38.20	1.3	1.1	3.0
Yellow	67.60	0.7	0.6	5.3
White	91.10	1.9	2.1	**7.2**
Coral	49.20	-	0.9	3.9
Light Blue	43.00	0.9	-	3.4
Purple	12.70	3.9	3.4	-
Brilliant Yellow-Green	54.90	1.1	1.3	4.3
Color Combination**	**Contrast Ratio***			
Orange & Black	13.2			
Red & White	6.2			
Blue & White	12.9			
White & Black	31.4			
Brilliant Yellow-Green and Black	18.9			

*A larger number denotes a greater contrast.

Table H-4. Contrast Ratios Calculated for Simulated Night Condition with Low-Beam Headlight at 30 Meters Using Original Ink Color Samples.

Color	Luminance Measurement (cd/m^2)	Contrast Ratio w/ Coral*	Contrast Ratio w/ Light Blue*	Contrast Ratio w/ Purple*
Black	5.48	**31.8**	**105.1**	**52.4**
Blue	56.00	3.1	**10.3**	**5.1**
Brown	150.00	1.2	3.8	1.9
Red	129.00	1.6	2.0	1.0
Green	282.00	1.3	4.5	2.2
Orange	386.00	2.2	1.5	1.3
Yellow	623.00	3.6	1.1	2.2
White	1950.00	**11.2**	3.4	6.8
Coral	174.00	-	3.3	1.6
Light Blue	576.00	3.3	-	2.0
Purple	287.00	1.6	2.0	-
Color Combination**	**Contrast Ratio***			
Orange & Black	70.4			
Red & White	6.9			
Blue & White	34.8			
White & Black	355.8			

*A larger number denotes a greater contrast.
**A luminance contrast value is not shown for brilliant yellow-green and black because color samples were not available at the time of measurement.

Table H-5. Contrast Ratios Calculated for Simulated Night Condition with Low-Beam Headlight at 90 Meters Using Original Ink Color Samples.

Color	Luminance Measurement (cd/m^2)	Luminance Contrast w/ Coral (%)*	Luminance Contrast w/ Light Blue (%)*	Luminance Contrast w/ Purple (%)*
Black	0.28	**72.5**	**206.8**	**111.1**
Blue	5.10	4.0	**11.4**	**6.1**
Brown	9.12	2.2	6.3	3.4
Red	12.50	1.4	2.0	1.1
Green	28.90	1.6	4.6	2.5
Orange	40.40	2.0	1.4	1.3
Yellow	73.90	3.6	1.3	2.4
White	94.20	**4.6**	1.6	3.0
Coral	20.30	-	2.9	1.5
Light Blue	57.90	2.9	-	1.9
Purple	31.10	1.5	1.9	-

Color Combination**	Luminance Contrast (%)*
Orange & Black	144.3
Red & White	3.3
Blue & White	18.5
White & Black	336.4

*A larger number denotes a greater contrast.
**A luminance contrast value is not shown for brilliant yellow-green and black because color samples were not available at the time of measurement.

APPENDIX I. 1976 CIE L*U*V* DISTANCE BETWEEN COLORS

Potential Legend Color	**Coral d*L*u*v***	**Light Blue d*L*u*v***	**Purple d*L*u*v***
Black	2118.0	1053.3	609.2
Blue	**3146.9**	**2085.3**	526.8
Brown	1969.7	995.5	687.6
Coral	-	1186.7	2550.0
Green	2070.8	888.5	1061.4
Light Blue	1186.7	-	1653.8
Orange	364.2	1495.8	2847.3
Purple	**2653.5**	1653.8	-
Red	1888.7	1161.8	880.0
White	543.9	1444.9	**3045.3**
Yellow	2522.7	**3605.2**	**5172.3**
Legend Color	**White d*L*u*v***	**Blue d*L*u*v***	**Orange d*L*u*v***
Red	2347.5	-	-
White	-	3511.4	-
Black	2471.4	-	2349.9
Legend Color	**Brilliant Yellow-Green d*L*u*v***		
Black	4639.3		
Purple	5239.1		

APPENDIX J. INITIAL CONTACT AND SCREENING FORMS FOR STUDY 1

VIRGINIA TECH CENTER FOR TRANSPORTATION RESEARCH
SIGN CONSPICUITY STUDY

INITIAL CONTACT SCRIPT (BY PHONE OR IN PERSON)

INTERVIEWER:*I am conducting an on-the-road study of traffic signs for my graduate research at Virginia Tech. The purpose of this research project is to evaluate traffic signs of varying colors and design parameters to determine which signs produce the greatest legibility, or reading, distance during day and night conditions on dry pavement.*

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. *Ride in a vehicle driven by one of our experimenters along an isolated test strip at the Virginia Tech airport in Blacksburg. This is the site at which data will be collected regarding sign reading distances.*

At the end of the experimental run, you will be driven back to the Center for Transportation Research, paid for your time, and debriefed. The total experiment time will be approximately 1 to 2 hours.

Would you be interested in participating?

POTENTIAL PARTICIPANT: YES or NO

INTERVIEWER:*As part of the experiment, I need to ask you a few questions. Your answers will help me determine if I can include you as a participant in my study and if so, it will also help me group and sort the data from the study. This data will not be associated with your name, and will be treated confidentially.*

See following pages.

VIRGINIA TECH CENTER FOR TRANSPORTATION RESEARCH
SIGN CONSPICUITY STUDY

INITIAL CONTACT SCREENING QUESTIONNAIRE AND BACKGROUND INFORMATION (BY PHONE)

Participant's Name:____Date of Birth:_________________
Participant's Phone No.:________ Gender: M or F
Eligibility Status:______________________ Date and Time:_______________________

For office use:	**Participant ID: ________**

NOTE TO INTERVIEWER: The initial screening consists of two parts: 1) demographic information and 2) health screening. Ask the participant the following questions and record his/her responses. If the participant does not have a valid driver's license, thank the person for his/her time and explain that this criteria must be met in order to participate. If the participant reveals a health condition that disqualifies him/her from safe participation in this study, thank the person for his/her time and explain that he/she is not eligible to participate for safety reasons.

PHONE INTERVIEWER: *As part of the study, I need to ask you a few questions. Your answers will determine your eligibility for this study. This data will not be associated with your name, and will be treated confidentially*.

1) To participate, you need to have a valid driver's license. Do you have a valid license?

YES NO

2) How many times per week do you drive?

4+ 2-3X 1X <1X

PHONE INTERVIEWER: If participant is eligible, then conduct the health screening.

See following pages.

VIRGINIA TECH CENTER FOR TRANSPORTATION RESEARCH
SIGN CONSPICUITY STUDY
Health Screening Questionnaire - Part I

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.)
   ____
   ____
   ____

Health Screening Questionnaire - Part I (cont'd)

3. (cont'd)

   Any disorders similar to the above or that would impair your driving ability (If yes, please describe.) Yes No

   ____
   ____
   ____

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

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

   ____
   ____
   ____

VIRGINIA TECH CENTER FOR TRANSPORTATION RESEARCH
SIGN CONSPICUITY STUDY

Health Screening Questionnaire - Part II (cont'd)

NOTE TO INTERVIEWER: This is part 2 of a two-part questionnaire. This part must be completed and signed immediately prior to participation in the study.

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

 ____
 ____

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

 ____
 ____

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

Yes No

________________________________ ________________________________
Signature Date

VIRGINIA TECH CENTER FOR TRANSPORTATION RESEARCH
SIGN CONSPICUITY STUDY

INITIAL CONTACT SCREENING QUESTIONNAIRE AND BACKGROUND INFORMATION (CONT'D)

PHONE INTERVIEWER: If participant is eligible based on results of background information and health screening...*Now I'd like to schedule a time when you can come out to the Center for the study*.
If participant is not eligible based on results of health screening...*Thank you for your time; unfortunately you are not eligible for this particular study due to safety considerations. Would you be interested on being put on a participant list for future studies?*

A. Schedule a time DATE AND TIME:______________________________

PHONE INTERVIEWER: If participant is eligible based on results of background information and health screening...*Do you have transportation to the Center, or do you need transportation? We can arrange for someone to pick you up and return you home afterwards*. If yes...*Please give me directions to the place where we will pick you up.*

____

____

____

____

PHONE INTERVIEWER: *Also, please refrain from drinking alcohol for the 24 hours before the experiment. Is this all right with you?* YES__________NO__________

PHONE INTERVIEWER: *I will call to remind you of when the experiment is scheduled. This reminder will occur approximately 24 hours before your appointment. At that time I will also include directions to the Center if necessary. Thank you! I'll see you* <insert date and time>.

comments:
____
____
____
____

APPENDIX K. INFORMED CONSENT FORM FOR STUDY 1

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

Title of the Project: Evaluation of Sign Design Parameters to Determine Improvements of Conspicuity for Traffic Signs

Investigators: Julie A. Barker, Dr. Vicki L. Neale, and Dr. Thomas A. Dingus

I. THE PURPOSE OF THIS RESEARCH

The purpose of this research project is to evaluate the effects of various traffic sign design parameters on sign visibility, conspicuity, and legibility. These terms refer to an observer's ability to detect, recognize, and interpret a traffic sign. The research includes the examination of 27 test signs made up of a specified set of colors and design parameters. Participants will examine signs from a slow-moving vehicle (5 mph) driven by an experimenter along an isolated test strip. For safety considerations, data collection will occur when on dry pavement and in the absence of other traffic. 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 twelve observers of varying age and gender.

II. PROCEDURES

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

1. Read and sign an Informed Consent Form.
2. Show a valid driver's license.
3. Complete a simple vision test and color vision test.
4. Complete a brief health screening questionnaire.
5. Ride in a vehicle to the test site.
6. Listen to the instructions regarding the task that you will be performing.
7. Ride in a slow-moving vehicle (5 mph) driven by an experimenter along a pre-determined test strip at the Virginia Tech airport in Blacksburg. This is the site at which data will be collected regarding sign reading distances.

At the end of the experimental run, you will be driven back to the Center for Transportation Research, paid for your time, and debriefed about the research. The total experiment time will be approximately 1 to 2 hours.

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 associated with being a passenger in an automobile.

(2) The slight additional risk of an accident that might possibly occur while riding in the vehicle when driven by the experimenter.

(3) Possible fatigue due to the length of the experiment. However, you will be given rest breaks during the experimental session.

The following precautions will be taken to ensure minimal risk to the you. Note, however, that the test vehicle will be driven in a marked-off area not in contact with other traffic.

(1) The experimenter driving the vehicle will be responsible for driving in a safe and 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 a fire extinguisher, first-aid kit, and a cellular phone, which may be used in an emergency.

(4) 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.

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 legibility distance 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 $23.00 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 <u>free to withdraw at any time</u> 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 Participants at Virginia Polytechnic Institute and State University and by the Virginia Tech Center for Transportation Research.

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 rules of this project.

____

Participant's Signature Date

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

Julie A. Barker, Investigator	(540) 961-7441
Vicki L. Neale, Project Manager	(540) 231-5578
Thomas A. Dingus, Principal Investigator	(540) 231-8831
H. T. Hurd, Chair, IRB	(540) 231-5281

APPENDIX L. VISION AND COLOR TESTS' SCRIPTS

VIRGINIA TECH CENTER FOR TRANSPORTATION RESEARCH
SIGN CONSPICUITY STUDY

VISION TEST AND COLOR VISION TEST
page 1 of 2

Participant ID: _______________	Date: ___________

After the participant has read and signed the consent form...

1) Administer "Health Screening Questionnaire" if not previously done.

NOTE TO EXPERIMENTER: Due to safety considerations, the participant must be in general good health, not be taking any medication that would adversely affect his/her driving ability (e.g., antihistamine), not have been drinking, and not be pregnant. Also note that the two vision tester devices described below provide the exact same testing materials, i.e., the tests are identical so that only one test record sheet is necessary when using either vision tester.

2) Follow me, and I'll administer a vision test that is required of all participants.

EXPERIMENTER: Take the participant to the area containing the vision tester. Have the participant sit DOWN and place his or her forehead against the headrest.

- If using the Optec 2000 Vision Tester -- The unit is activated/illuminated when the participant places forehead against headrest trigger. The GREEN "READY" indicator on the control panel should be lit at this point. Set the dial to #2 at the yellow indicator (FAR). Make sure the participant is wearing any glasses or contacts necessary for distance vision (as in for driving).
- If using the Titmus® II Vision Tester -- Set the control pad such that both OCCLUDER pads are OFF, the FAR light is ON, and the No. 2 test light is ON.

Read to participant: *Look at the target No. 1: is the ring at the TOP broken like the other rings, or is it unbroken?*

EXPERIMENTER: Let participant answer TOP, BOTTOM, LEFT, or RIGHT. {Answers are on the score sheet -- T, B, L, R.} *Where is the unbroken ring in target no. 2? no. 3? no. 4?* Continue until the subject misses two consecutive answers. When the participant misses one, but answers the next one correctly, continue until the subject misses two consecutive answers. Record the acuity of the last target that he or she gets correct. If the participant does not understand the instruction, refer to the acuity demonstrator page.

Acuity score: _______________

VISION TEST AND COLOR VISION TEST

Participant ID: _______________	Date: ___________

EXPERIMENTER: Consists of 6 accurately reproduced Ishihara Pseudo-Isochromatic Plates. This test detects the presence of a color deficiency but does not classify as to type. A total of eight digits can be seen by color-normal individuals in the 6 circles.

- If using the Optec 2000 Vision Tester -- Set the dial to #6 at the yellow indicator (far) for the color vision test.
- If using the Titmus® II Vision Tester -- Set the control pad such that both OCCLUDER pads are OFF, the FAR light is ON, and the No. 6 test light is ON.

Read to participant: *Next I'll administer a color vision test that is required of all participants. Do you see a numeral in circle A? What numeral do you see?*

EXPERIMENTER: Repeat for circles B, C, D, E, and F. The correct response for circle F would be no number. Eight digits are displayed in a total of six circles.

- Normal: 8 digits correct.
- Mild deficiency: 5 or more digits correct.
- FAIL: less than 5 digits correct. Record on line below number of letters or numbers correctly identified and the score (normal, mild deficiency, or fail).

Color test score: _______________

SCORING

In order for the participant to continue with the study, the participant must:

A. Have a visual acuity of 20/40 or better, corrected with glasses or contact lenses as necessary.
B. Pass "Health Screening Questionnaire." For Question 3, look for impairments that might adversely affect one's ability to drive.
C. Regarding the color vision, several participants should have some form of color deficiency (mild or fail) as demonstrated by the color vision test criteria. Remaining participants should have normal color vision.

Vision Tester Record Form

Participant ID:______
Date: ___________________
Age: ___________________
M____ F_____
Contact Lenses: Yes___ No___
Bifocals:___________ Trifocals:_____
Special:___________________
Comments:____

Test No.	Target	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	**Both Eyes**	T	R	R	L	T	B	L	R	L	B	R	B	T	R
3	**Right**	T	L	T	T	B	B	L	B	R	T	R	L	B	R
4	**Left**	L	R	L	B	R	T	T	B	R	T	B	R	T	L
Snellen Equivalents		20/200	20/100	20/70	20/50	20/40	20/35	20/30	20/25	20/22	20/20	20/18	20/17	20/15	20/13
Test No.	**Target**	**A**	**B**	**C**	**D**	**E**	**F**								
6	**Color**	12	5	26	6	16	0								

APPENDIX M. SCRIPTS OF TEST INSTRUCTIONS AND PROCEDURES FOR STUDY 1

Center for Transportation Research
Virginia Tech
Sign Conspicuity Study

Experimenter's Instructions Script

1. INTRODUCTIONS and INSTRUCTIONS

A. Greet Participant

B. Informed Consent Form

- *Give participant a copy of the informed consent form to read.*
- *Answer any general questions the participant might have about the study.*
- *Have participant sign and date the informed consent form.*
- *Give participant a copy of the informed consent form.*

C. Verify Driver's License

- *Have participant show a valid driver's license.*

D. Health, Medication, and Drug Questionnaire

- *Give participant a copy of the health, medication, and drug questionnaire to complete.*
- *Have participant sign and date the health, medication, and drug questionnaire.*
- *Review questionnaire to ensure that participant is fit to take part in the study.*

E. Vision Test and Color Vision Test

EXPERIMENTER: "Before we go out to the vehicle, I need to give you a vision test. This is a requirement of all participants of this study."

- *Administer vision test and color vision test per instructions provided by Vision and Color Tests' Scripts.*
- *Review results of both tests to ensure that participant is fit to take part in the study.*
- *If passes (at least 20/40 and meets required level of color vision), then go out to vehicle and continue with study. If fails, pay for time and excuse from study.*

F. Initial Briefing

EXPERIMENTER: "Do you have any questions at this point in time?"

- *Answer any general questions the participant might have.*

EXPERIMENTER: "Before we proceed, I would like to tell you that I will be reading from a script during much of our time together. This ensures that I will not forget to tell you anything. So, if I sound extremely formal at times, please understand that this is a requirement of the study."

G. Vehicle Briefing

- *Open front passenger side door for the participant and have him or her get into the front passenger seat.*
- *Get into front driver's side seat.*

EXPERIMENTER: "Before we begin today, I would like to take a few moments to familiarize you with this vehicle. Please note that, for your safety, this car is equipped with ABS brakes and driver's side and passenger's side airbags. Are you aware of these technologies?"

- *If not, explain.*

EXPERIMENTER: "Now, I would like you to adjust the seat so that you are in a comfortable position, and please fasten your seatbelt.

- *Show seat adjustments and have the participant adjust the seat. Then have him/her fasten his/her seatbelt.*

H. Task Training

EXPERIMENTER: "In order to make the experiment as objective and safe as possible, I would like to go over a few points before we start driving."

"You will be driven in our vehicle along a test strip at the Virginia Tech airport in Blacksburg. Test traffic signs will be placed at either end of the tarmac. The vehicle will be driven at approximately 5 mph toward a traffic sign. Your task is to watch for the traffic sign and indicate when you are able to read the words contained on the sign. Note that the words <u>will not</u> be typical of road signs. When you believe that you can read the words, please indicate this by saying, "Stop." After the vehicle has stopped, you will be asked to say the words that you see on the sign and identify the direction in which the arrow on the sign is pointing. If you are correct, the trial is over and the vehicle will be turned around for the next trial run. In addition, the distance to the sign will be measured by me using the data collection computer. If you are incorrect, the vehicle will begin moving toward the sign again. When you believe that you can read the message, please indicate this by saying, "Stop." After the vehicle has stopped, you will again be asked to say the words that you see on the sign and identify the direction in which the arrow on the sign is pointing. This procedure will be repeated until you are able to correctly identify the words on the sign.

"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 or are unable to read a 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.

"There are a total of 27 signs plus two practice signs, and this procedure must be repeated for each sign. If you become tired and need a rest period, or need to get out of the vehicle and walk around, please indicate so."

"Do you have any questions before we go out to the vehicle?"

- *Answer any general questions the participant might have.*

2. PRACTICE SESSION

EXPERIMENTER: "Now we will begin a practice run to help you get familiar with the procedure. An example test sign will be placed at the other end of the tarmac. Your task is to watch for the sign and indicate when you are able to read the words it contains. When you believe that you can read the words, please indicate this by saying, “Stop.” After the vehicle has stopped, you will be asked to say the words that you see on the sign and identify the direction in which the arrow on the sign is pointing. If you are correct, the trial is over and the vehicle will be turned around so that we may start the data collection session. In addition, the distance to the sign will be measured by an experimenters. If you are incorrect, the vehicle will begin moving toward the sign again. When you believe that you can read the message, please indicate this by saying, “Stop.” After the vehicle has stopped, you will again be asked to say the words that you see on the sign and identify the direction in which the arrow on the sign is pointing. This procedure will be repeated until you are able to correctly identify the words on the sign.

EXPERIMENTER: "Are you ready to begin the test drive?"

- *Drive along test strip until participant identifies example test sign message. Then reposition vehicle for data collection session.*

3. DATA COLLECTION

EXPERIMENTER: "Your task is to identify the sign contents and arrow direction as soon as you are able. After each trial, you will then answer several simple survey questions regarding your ability to see and read the sign. There are no other tasks associated with this study."

"Do you have any questions about these tasks? Please note that neither I nor <name> (the other experimenters) will be allowed to answer questions while the drive is ongoing. Also, we will not be able to talk with you during the drive.”

- *Answer general questions.*

- *Begin preparing data collection materials.*
  (1) Enter subject number.
  (2) Enter input condition.
  (3) Begin data collection.

4. POST-TEST, DEBRIEFING, AND PAYMENT

- *Return to the CTR*

- *Answer any questions the participant has during the debriefing or about the study in general.*

- *Pay participant. Make sure that both you and the participant sign/date the payment log sheet.*

- *Thank participant for taking part in the study*

Center for Transportation Research
Virginia Tech
Sign Conspicuity Study

Second & Third Experimenters' Protocol

Tasks

- The second experimenter has one primary task, which is described as follows:

  Exchange test signs according to the designated order. Test signs will be changed after completion of a trial run and observance of a signal from the in-vehicle experimenter indicating the end of the run. The order of sign presentation will be predetermined for each participant prior to the data collection session.

- The third experimenter has one primary task, which is described as follows:

  Exchange test signs according to the designated order. Test signs will be changed after completion of a trial run and observance of a signal from the in-vehicle experimenter indicating the end of the run. The order of sign presentation will be predetermined for each participant prior to the data collection session.

APPENDIX N. ORDER OF SIGN PRESENTATION IN STUDY 1

Sign Presentation for July 2, 1997, Evening.

Present Order	**Post Location****	**Spec.* ID #**	**Colors†**	**Legend**	**Arrow†† Direction**
1	Terminal		*FL. o/blk‡*	*EMERGENCY DETOUR*	R
2	Road	20	p/wh	FARM GAME GROUND	U
3	Terminal	6	c/blk	TEMPORARY ROUTES	R
4	Road	8	c/blu	MY PERCENT REACTS	R
5	Terminal	18	p/blk	END MARKER COUNTS	U
6	Road	22	p/y	GAS METER STORED	R
7	Terminal	2	o/blk	YOUNG MEN TROUPE	L
8	Road	10	c/wh	LEGENDARY TRULY	U
9	Terminal	13	Lblu/blk	REMOTELY OUTER	R
10	Road	27	p/yg	MONDAY COURSE	U
11	Terminal	25	yg/blk	DECEMBER ROUNDS	R
12	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
13	Terminal	11	c/wh	A MOTOR DEPART	U
14	Road	5	r/wh/blu	DOCUMENT VOTED	R
15	Terminal	23	p/y	WELCOME DO RUN	L
16	Road	9	c/blu	NOVEMBER DROVE	U
17	Terminal	17	Lblu/y	MODERN POCKET	R
18	Road	21	p/wh	WED THRU TRUDGE	L
19	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
20	Road	4	r/wh/blu	ME ENERGY READY	R
21	Terminal	19	p/blk	RED GLOW DOCTOR	L
22	Road	16	Lblu/y	MY GRADES RACKET	U
23	Terminal	7	c/blk	FOR GREEN TOWERS	L
24	Road	3	o/blk	METROBUS TOURED	U
25	Terminal	24	yg/blk	GOT EMPTY BATONS	R
26	Road	14	Lblu/blu	WORKER GO URGENT	R
27	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
28	Road	26	p/yg	CAMPER ON UNDOCK	L

The following applies for all tables in Appendix G:
*Number corresponds to identification number listed in Appendix A.
**Road = Southwest end of test strip; Terminal = Northeast end of test strip.
†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.
††L = left, R = right, U = up or forward.
‡A fluorescent orange and black sign was used during the data collection sessions, but this color scheme was not included in the color schemes of interest in this study.

Sign Presentation for July 3, 1997, Morning.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Road	5	r/wh/blu	DOCUMENT VOTED	R
2	Terminal	17	Lblu/y	MODERN POCKET	R
3	Road	9	c/blu	NOVEMBER DROVE	U
4	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
5	Road	21	p/wh	WED THRU TRUDGE	L
6	Terminal	19	p/blk	RED GLOW DOCTOR	L
7	Road	4	r/wh/blu	ME ENERGY READY	R
8	Terminal	7	c/blk	FOR GREEN TOWERS	L
9	Road	16	Lblu/y	MY GRADES RACKET	U
10	Terminal	24	yg/blk	GOT EMPTY BATONS	R
11	Road	3	o/blk	METROBUS TOURED	U
12	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
13	Road	14	Lblu/blu	WORKER GO URGENT	R
14	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
15	Road	26	p/yg	CAMPER ON UNDOCK	L
16	Terminal	6	c/blk	TEMPORARY ROUTES	R
17	Road	20	p/wh	FARM GAME GROUND	U
18	Terminal	18	p/blk	END MARKER COUNTS	U
19	Road	8	c/blu	MY PERCENT REACTS	R
20	Terminal	2	o/blk	YOUNG MEN TROUPE	L
21	Road	22	p/y	GAS METER STORED	R
22	Terminal	13	Lblu/blk	REMOTELY OUTER	R
23	Road	10	c/wh	LEGENDARY TRULY	U
24	Terminal	25	yg/blk	DECEMBER ROUNDS	R
25	Road	27	p/yg	MONDAY COURSE	U
26	Terminal	11	c/wh	A MOTOR DEPART	U
27	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
28	Terminal	23	p/y	WELCOME DO RUN	L

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 8, 1997, Night.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
2	Terminal	23	p/y	WELCOME DO RUN	L
3	Road	5	r/wh/blu	DOCUMENT VOTED	R
4	Terminal	17	Lblu/y	MODERN POCKET	R
5	Road	9	c/blu	NOVEMBER DROVE	U
6	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
7	Road	21	p/wh	WED THRU TRUDGE	L
8	Terminal	19	p/blk	RED GLOW DOCTOR	L
9	Road	4	r/wh/blu	ME ENERGY READY	R
10	Terminal	7	c/blk	FOR GREEN TOWERS	L
11	Road	16	Lblu/y	MY GRADES RACKET	U
12	Terminal	24	yg/blk	GOT EMPTY BATONS	R
13	Road	3	o/blk	METROBUS TOURED	U
14	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
15	Road	14	Lblu/blu	WORKER GO URGENT	R
16	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
17	Road	26	p/yg	CAMPER ON UNDOCK	L
18	Terminal	6	c/blk	TEMPORARY ROUTES	R
19	Road	20	p/wh	FARM GAME GROUND	U
20	Terminal	18	p/blk	END MARKER COUNTS	U
21	Road	8	c/blu	MY PERCENT REACTS	R
22	Terminal	2	o/blk	YOUNG MEN TROUPE	L
23	Road	22	p/y	GAS METER STORED	R
24	Terminal	13	Lblu/blk	REMOTELY OUTER	R
25	Road	10	c/wh	LEGENDARY TRULY	U
26	Terminal	25	yg/blk	DECEMBER ROUNDS	R
27	Road	27	p/yg	MONDAY COURSE	U
28	Terminal	11	c/wh	A MOTOR DEPART	U

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 9, 1997, Morning.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Road	8	c/blu	MY PERCENT REACTS	R
2	Terminal	2	o/blk	YOUNG MEN TROUPE	L
3	Road	22	p/y	GAS METER STORED	R
4	Terminal	13	Lblu/blk	REMOTELY OUTER	R
5	Road	10	c/wh	LEGENDARY TRULY	U
6	Terminal	25	yg/blk	DECEMBER ROUNDS	R
7	Road	27	p/yg	MONDAY COURSE	U
8	Terminal	11	c/wh	A MOTOR DEPART	U
9	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
10	Terminal	23	p/y	WELCOME DO RUN	L
11	Road	5	r/wh/blu	DOCUMENT VOTED	R
12	Terminal	17	Lblu/y	MODERN POCKET	R
13	Road	9	c/blu	NOVEMBER DROVE	U
14	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
15	Road	21	p/wh	WED THRU TRUDGE	L
16	Terminal	19	p/blk	RED GLOW DOCTOR	L
17	Road	4	r/wh/blu	ME ENERGY READY	R
18	Terminal	7	c/blk	FOR GREEN TOWERS	L
19	Road	16	Lblu/y	MY GRADES RACKET	U
20	Terminal	24	yg/blk	GOT EMPTY BATONS	R
21	Road	3	o/blk	METROBUS TOURED	U
22	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
23	Road	14	Lblu/blu	WORKER GO URGENT	R
17	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
25	Road	26	p/yg	CAMPER ON UNDOCK	L
26	Terminal	6	c/blk	TEMPORARY ROUTES	R
27	Road	20	p/wh	FARM GAME GROUND	U
28	Terminal	18	p/blk	END MARKER COUNTS	U

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 9, 1997, Evening; July 24, 1997, Early Evening.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Terminal	11	c/wh	A MOTOR DEPART	U
2	Road	5	r/wh/blu	DOCUMENT VOTED	R
3	Terminal	23	p/y	WELCOME DO RUN	L
4	Road	9	c/blu	NOVEMBER DROVE	U
5	Terminal	17	Lblu/y	MODERN POCKET	R
6	Road	21	p/wh	WED THRU TRUDGE	L
7	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
8	Road	4	r/wh/blu	ME ENERGY READY	R
9	Terminal	19	p/blk	RED GLOW DOCTOR	L
10	Road	16	Lblu/y	MY GRADES RACKET	U
11	Terminal	7	c/blk	FOR GREEN TOWERS	L
12	Road	3	o/blk	METROBUS TOURED	U
13	Terminal	24	yg/blk	GOT EMPTY BATONS	R
14	Road	14	Lblu/blu	WORKER GO URGENT	R
15	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
16	Road	26	p/yg	CAMPER ON UNDOCK	L
17	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
18	Road	20	p/wh	FARM GAME GROUND	U
19	Terminal	6	c/blk	TEMPORARY ROUTES	R
20	Road	8	c/blu	MY PERCENT REACTS	R
21	Terminal	18	p/blk	END MARKER COUNTS	U
22	Road	22	p/y	GAS METER STORED	R
23	Terminal	2	o/blk	YOUNG MEN TROUPE	L
24	Road	10	c/wh	LEGENDARY TRULY	U
25	Terminal	13	Lblu/blk	REMOTELY OUTER	R
26	Road	27	p/yg	MONDAY COURSE	U
27	Terminal	25	yg/blk	DECEMBER ROUNDS	R
28	Road	15	Lblu/blu	PAYMENTS DEVOTE	L

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 10, 1997, Morning.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Road	14	Lblu/blu	WORKER GO URGENT	R
2	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
3	Road	26	p/yg	CAMPER ON UNDOCK	L
4	Terminal	6	c/blk	TEMPORARY ROUTES	R
5	Road	20	p/wh	FARM GAME GROUND	U
6	Terminal	18	p/blk	END MARKER COUNTS	U
7	Road	8	c/blu	MY PERCENT REACTS	R
8	Terminal	2	o/blk	YOUNG MEN TROUPE	L
9	Road	22	p/y	GAS METER STORED	R
10	Terminal	13	Lblu/blk	REMOTELY OUTER	R
11	Road	10	c/wh	LEGENDARY TRULY	U
12	Terminal	25	yg/blk	DECEMBER ROUNDS	R
13	Road	27	p/yg	MONDAY COURSE	U
14	Terminal	11	c/wh	A MOTOR DEPART	U
15	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
16	Terminal	23	p/y	WELCOME DO RUN	L
17	Road	5	r/wh/blu	DOCUMENT VOTED	R
18	Terminal	17	Lblu/y	MODERN POCKET	R
19	Road	9	c/blu	NOVEMBER DROVE	U
20	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
21	Road	21	p/wh	WED THRU TRUDGE	L
22	Terminal	19	p/blk	RED GLOW DOCTOR	L
23	Road	4	r/wh/blu	ME ENERGY READY	R
24	Terminal	7	c/blk	FOR GREEN TOWERS	L
25	Road	16	Lblu/y	MY GRADES RACKET	U
26	Terminal	24	yg/blk	GOT EMPTY BATONS	R
27	Road	3	o/blk	METROBUS TOURED	U
28	Terminal	12	Lblu/blk	ENTER NOW YONDER	L

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 10, 1997, Night.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
2	Road	26	p/yg	CAMPER ON UNDOCK	L
3	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
4	Road	20	p/wh	FARM GAME GROUND	U
5	Terminal	6	c/blk	TEMPORARY ROUTES	R
6	Road	8	c/blu	MY PERCENT REACTS	R
7	Terminal	18	p/blk	END MARKER COUNTS	U
8	Road	22	p/y	GAS METER STORED	R
9	Terminal	2	o/blk	YOUNG MEN TROUPE	L
10	Road	10	c/wh	LEGENDARY TRULY	U
11	Terminal	13	Lblu/blk	REMOTELY OUTER	R
12	Road	27	p/yg	MONDAY COURSE	U
13	Terminal	25	yg/blk	DECEMBER ROUNDS	R
14	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
15	Terminal	11	c/wh	A MOTOR DEPART	U
16	Road	5	r/wh/blu	DOCUMENT VOTED	R
17	Terminal	23	p/y	WELCOME DO RUN	L
18	Road	9	c/blu	NOVEMBER DROVE	U
19	Terminal	17	Lblu/y	MODERN POCKET	R
20	Road	21	p/wh	WED THRU TRUDGE	L
21	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
22	Road	4	r/wh/blu	ME ENERGY READY	R
23	Terminal	19	p/blk	RED GLOW DOCTOR	L
24	Road	16	Lblu/y	MY GRADES RACKET	U
25	Terminal	7	c/blk	FOR GREEN TOWERS	L
26	Road	3	o/blk	METROBUS TOURED	U
27	Terminal	24	yg/blk	GOT EMPTY BATONS	R
28	Road	14	Lblu/blu	WORKER GO URGENT	R

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 11, 1997, Evening.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Terminal	18	p/blk	END MARKER COUNTS	U
2	Road	22	p/y	GAS METER STORED	R
3	Terminal	2	o/blk	YOUNG MEN TROUPE	L
4	Road	10	c/wh	LEGENDARY TRULY	U
5	Terminal	13	Lblu/blk	REMOTELY OUTER	R
6	Road	27	p/yg	MONDAY COURSE	U
7	Terminal	25	yg/blk	DECEMBER ROUNDS	R
8	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
9	Terminal	11	c/wh	A MOTOR DEPART	U
10	Road	5	r/wh/blu	DOCUMENT VOTED	R
11	Terminal	23	p/y	WELCOME DO RUN	L
12	Road	9	c/blu	NOVEMBER DROVE	U
13	Terminal	17	Lblu/y	MODERN POCKET	R
14	Road	21	p/wh	WED THRU TRUDGE	L
15	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
16	Road	4	r/wh/blu	ME ENERGY READY	R
17	Terminal	19	p/blk	RED GLOW DOCTOR	L
18	Road	16	Lblu/y	MY GRADES RACKET	U
19	Terminal	7	c/blk	FOR GREEN TOWERS	L
20	Road	3	o/blk	METROBUS TOURED	U
21	Terminal	24	yg/blk	GOT EMPTY BATONS	R
22	Road	14	Lblu/blu	WORKER GO URGENT	R
23	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
24	Road	26	p/yg	CAMPER ON UNDOCK	L
25	Terminal		*o/blk*	*EMERGENCY DETOUR*	R
26	Road	20	p/wh	FARM GAME GROUND	U
27	Terminal	6	c/blk	TEMPORARY ROUTES	R
28	Road	8	c/blu	MY PERCENT REACTS	R

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 12, 1997, Night.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Terminal	19	p/blk	RED GLOW DOCTOR	L
2	Road	16	Lblu/y	MY GRADES RACKET	U
3	Terminal	7	c/blk	FOR GREEN TOWERS	L
4	Road	3	o/blk	METROBUS TOURED	U
5	Terminal	24	yg/blk	GOT EMPTY BATONS	R
6	Road	14	Lblu/blu	WORKER GO URGENT	R
7	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
8	Road	26	p/yg	CAMPER ON UNDOCK	L
9	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
10	Road	20	p/wh	FARM GAME GROUND	U
11	Terminal	6	c/blk	TEMPORARY ROUTES	R
12	Road	8	c/blu	MY PERCENT REACTS	R
13	Terminal	18	p/blk	END MARKER COUNTS	U
14	Road	22	p/y	GAS METER STORED	R
15	Terminal	2	o/blk	YOUNG MEN TROUPE	L
16	Road	10	c/wh	LEGENDARY TRULY	U
17	Terminal	13	Lblu/blk	REMOTELY OUTER	R
18	Road	27	p/yg	MONDAY COURSE	U
19	Terminal	25	yg/blk	DECEMBER ROUNDS	R
20	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
21	Terminal	11	c/wh	A MOTOR DEPART	U
22	Road	5	r/wh/blu	DOCUMENT VOTED	R
23	Terminal	23	p/y	WELCOME DO RUN	L
24	Road	9	c/blu	NOVEMBER DROVE	U
25	Terminal	17	Lblu/y	MODERN POCKET	R
26	Road	21	p/wh	WED THRU TRUDGE	L
27	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
28	Road	4	r/wh/blu	ME ENERGY READY	R

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 14, 1997, Morning.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Road	16	Lblu/y	MY GRADES RACKET	U
2	Terminal	24	yg/blk	GOT EMPTY BATONS	R
3	Road	3	o/blk	METROBUS TOURED	U
4	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
5	Road	14	Lblu/blu	WORKER GO URGENT	R
6	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
7	Road	26	p/yg	CAMPER ON UNDOCK	L
8	Terminal	6	c/blk	TEMPORARY ROUTES	R
9	Road	20	p/wh	FARM GAME GROUND	U
10	Terminal	18	p/blk	END MARKER COUNTS	U
11	Road	8	c/blu	MY PERCENT REACTS	R
12	Terminal	2	o/blk	YOUNG MEN TROUPE	L
13	Road	22	p/y	GAS METER STORED	R
14	Terminal	13	Lblu/blk	REMOTELY OUTER	R
15	Road	10	c/wh	LEGENDARY TRULY	U
16	Terminal	25	yg/blk	DECEMBER ROUNDS	R
17	Road	27	p/yg	MONDAY COURSE	U
18	Terminal	11	c/wh	A MOTOR DEPART	U
19	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
20	Terminal	23	p/y	WELCOME DO RUN	L
21	Road	5	r/wh/blu	DOCUMENT VOTED	R
22	Terminal	17	Lblu/y	MODERN POCKET	R
23	Road	9	c/blu	NOVEMBER DROVE	U
24	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
25	Road	21	p/wh	WED THRU TRUDGE	L
26	Terminal	19	p/blk	RED GLOW DOCTOR	L
27	Road	4	r/wh/blu	ME ENERGY READY	R
28	Terminal	7	c/blk	FOR GREEN TOWERS	L

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 14, 1997, Night.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Road	20	p/wh	FARM GAME GROUND	U
2	Terminal	18	p/blk	END MARKER COUNTS	U
3	Road	8	c/blu	MY PERCENT REACTS	R
4	Terminal	2	o/blk	YOUNG MEN TROUPE	L
5	Road	22	p/y	GAS METER STORED	R
6	Terminal	13	Lblu/blk	REMOTELY OUTER	R
7	Road	10	c/wh	LEGENDARY TRULY	U
8	Terminal	25	yg/blk	DECEMBER ROUNDS	R
9	Road	27	p/yg	MONDAY COURSE	U
10	Terminal	11	c/wh	A MOTOR DEPART	U
11	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
12	Terminal	23	p/y	WELCOME DO RUN	L
13	Road	5	r/wh/blu	DOCUMENT VOTED	R
14	Terminal	17	Lblu/y	MODERN POCKET	R
15	Road	9	c/blu	NOVEMBER DROVE	U
16	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
17	Road	21	p/wh	WED THRU TRUDGE	L
18	Terminal	19	p/blk	RED GLOW DOCTOR	L
19	Road	4	r/wh/blu	ME ENERGY READY	R
20	Terminal	7	c/blk	FOR GREEN TOWERS	L
21	Road	16	Lblu/y	MY GRADES RACKET	U
22	Terminal	24	yg/blk	GOT EMPTY BATONS	R
23	Road	3	o/blk	METROBUS TOURED	U
24	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
25	Road	14	Lblu/blu	WORKER GO URGENT	R
26	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
27	Road	26	p/yg	CAMPER ON UNDOCK	L
28	Terminal	6	c/blk	TEMPORARY ROUTES	R

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 15, 1997, Evening.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
2	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
3	Road	4	r/wh/blu	ME ENERGY READY	R
4	Terminal	19	p/blk	RED GLOW DOCTOR	L
5	Road	9	c/blu	NOVEMBER DROVE	U
6	Terminal	7	c/blk	FOR GREEN TOWERS	L
7	Road	16	Lblu/y	MY GRADES RACKET	U
8	Terminal	24	yg/blk	GOT EMPTY BATONS	R
9	Road	3	o/blk	METROBUS TOURED	U
10	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
11	Road	14	Lblu/blu	WORKER GO URGENT	R
12	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
13	Road	26	p/yg	CAMPER ON UNDOCK	L
14	Terminal	6	c/blk	TEMPORARY ROUTES	R
15	Road	20	p/wh	FARM GAME GROUND	U
16	Terminal	18	p/blk	END MARKER COUNTS	U
17	Road	8	c/blu	MY PERCENT REACTS	R
18	Terminal	2	o/blk	YOUNG MEN TROUPE	L
19	Road	22	p/y	GAS METER STORED	R
20	Terminal	13	Lblu/blk	REMOTELY OUTER	R
21	Road	10	c/wh	LEGENDARY TRULY	U
22	Terminal	25	yg/blk	DECEMBER ROUNDS	R
23	Road	21	p/wh	WED THRU TRUDGE	L
24	Terminal	11	c/wh	A MOTOR DEPART	U
25	Road	5	r/wh/blu	DOCUMENT VOTED	R
26	Terminal	23	p/y	WELCOME DO RUN	L
27	Road	27	p/yg	MONDAY COURSE	U
28	Terminal	17	Lblu/y	MODERN POCKET	R

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 15, 1997, Evening.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
2	Road	3	o/blk	METROBUS TOURED	U
3	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
4	Road	14	Lblu/blu	WORKER GO URGENT	R
5	Terminal	7	c/blk	FOR GREEN TOWERS	L
6	Road	26	p/yg	CAMPER ON UNDOCK	L
7	Terminal	24	yg/blk	GOT EMPTY BATONS	R
8	Road	20	p/wh	FARM GAME GROUND	U
9	Terminal	6	c/blk	TEMPORARY ROUTES	R
10	Road	8	c/blu	MY PERCENT REACTS	R
11	Terminal	18	p/blk	END MARKER COUNTS	U
12	Road	22	p/y	GAS METER STORED	R
13	Terminal	2	o/blk	YOUNG MEN TROUPE	L
14	Road	10	c/wh	LEGENDARY TRULY	U
15	Terminal	13	Lblu/blk	REMOTELY OUTER	R
16	Road	27	p/yg	MONDAY COURSE	U
17	Terminal	25	yg/blk	DECEMBER ROUNDS	R
18	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
19	Terminal	11	c/wh	A MOTOR DEPART	U
20	Road	5	r/wh/blu	DOCUMENT VOTED	R
21	Terminal	23	p/y	WELCOME DO RUN	L
22	Road	9	c/blu	NOVEMBER DROVE	U
23	Terminal	17	Lblu/y	MODERN POCKET	R
24	Road	21	p/wh	WED THRU TRUDGE	L
25	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
26	Road	4	r/wh/blu	ME ENERGY READY	R
27	Terminal	19	p/blk	RED GLOW DOCTOR	L
28	Road	16	Lblu/y	MY GRADES RACKET	U

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 15, 1997, Night.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Road	22	p/y	GAS METER STORED	R
2	Terminal	13	Lblu/blk	REMOTELY OUTER	R
3	Road	10	c/wh	LEGENDARY TRULY	U
4	Terminal	25	yg/blk	DECEMBER ROUNDS	R
5	Road	27	p/yg	MONDAY COURSE	U
6	Terminal	11	c/wh	A MOTOR DEPART	U
7	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
8	Terminal	23	p/y	WELCOME DO RUN	L
9	Road	5	r/wh/blu	DOCUMENT VOTED	R
10	Terminal	17	Lblu/y	MODERN POCKET	R
11	Road	9	c/blu	NOVEMBER DROVE	U
12	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
13	Road	21	p/wh	WED THRU TRUDGE	L
14	Terminal	19	p/blk	RED GLOW DOCTOR	L
15	Road	4	r/wh/blu	ME ENERGY READY	R
16	Terminal	7	c/blk	FOR GREEN TOWERS	L
17	Road	16	Lblu/y	MY GRADES RACKET	U
18	Terminal	24	yg/blk	GOT EMPTY BATONS	R
19	Road	3	o/blk	METROBUS TOURED	U
20	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
21	Road	14	Lblu/blu	WORKER GO URGENT	R
22	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
23	Road	26	p/yg	CAMPER ON UNDOCK	L
24	Terminal	6	c/blk	TEMPORARY ROUTES	R
25	Road	20	p/wh	FARM GAME GROUND	U
26	Terminal	18	p/blk	END MARKER COUNTS	U
27	Road	8	c/blu	MY PERCENT REACTS	R
28	Terminal	2	o/blk	YOUNG MEN TROUPE	L

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 17, 1997, Night.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Terminal	17	Lblu/y	MODERN POCKET	R
2	Road	21	p/wh	WED THRU TRUDGE	L
3	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
4	Road	4	r/wh/blu	ME ENERGY READY	R
5	Terminal	19	p/blk	RED GLOW DOCTOR	L
6	Road	16	Lblu/y	MY GRADES RACKET	U
7	Terminal	7	c/blk	FOR GREEN TOWERS	L
8	Road	3	o/blk	METROBUS TOURED	U
9	Terminal	24	yg/blk	GOT EMPTY BATONS	R
10	Road	14	Lblu/blu	WORKER GO URGENT	R
11	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
12	Road	26	p/yg	CAMPER ON UNDOCK	L
13	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
14	Road	20	p/wh	FARM GAME GROUND	U
15	Terminal	6	c/blk	TEMPORARY ROUTES	R
16	Road	8	c/blu	MY PERCENT REACTS	R
17	Terminal	18	p/blk	END MARKER COUNTS	U
18	Road	22	p/y	GAS METER STORED	R
19	Terminal	2	o/blk	YOUNG MEN TROUPE	L
20	Road	10	c/wh	LEGENDARY TRULY	U
21	Terminal	13	Lblu/blk	REMOTELY OUTER	R
22	Road	27	p/yg	MONDAY COURSE	U
23	Terminal	25	yg/blk	DECEMBER ROUNDS	R
24	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
25	Terminal	11	c/wh	A MOTOR DEPART	U
26	Road	5	r/wh/blu	DOCUMENT VOTED	R
27	Terminal	23	p/y	WELCOME DO RUN	L
28	Road	9	c/blu	NOVEMBER DROVE	U

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

Sign Presentation for July 19, 1997, Night.

Present Order	Post Location	Spec.* ID #	Colors†	Legend	Arrow Direction
1	Terminal	25	yg/blk	DECEMBER ROUNDS	R
2	Road	15	Lblu/blu	PAYMENTS DEVOTE	L
3	Terminal	11	c/wh	A MOTOR DEPART	U
4	Road	5	r/wh/blu	DOCUMENT VOTED	R
5	Terminal	23	p/y	WELCOME DO RUN	L
6	Road	9	c/blu	NOVEMBER DROVE	U
7	Terminal	17	Lblu/y	MODERN POCKET	R
8	Road	21	p/wh	WED THRU TRUDGE	L
9	Terminal	*1*	r/wh/blu	*EMERGENCY DETOUR*	R
10	Road	4	r/wh/blu	ME ENERGY READY	R
11	Terminal	19	p/blk	RED GLOW DOCTOR	L
12	Road	16	Lblu/y	MY GRADES RACKET	U
13	Terminal	7	c/blk	FOR GREEN TOWERS	L
14	Road	3	o/blk	METROBUS TOURED	U
15	Terminal	24	yg/blk	GOT EMPTY BATONS	R
16	Road	14	Lblu/blu	WORKER GO URGENT	R
17	Terminal	12	Lblu/blk	ENTER NOW YONDER	L
18	Road	26	p/yg	CAMPER ON UNDOCK	L
19	Terminal		*FL. o/blk*	*EMERGENCY DETOUR*	R
20	Road	20	p/wh	FARM GAME GROUND	U
21	Terminal	6	c/blk	TEMPORARY ROUTES	R
22	Road	8	c/blu	MY PERCENT REACTS	R
23	Terminal	18	p/blk	END MARKER COUNTS	U
24	Road	22	p/y	GAS METER STORED	R
25	Terminal	2	o/blk	YOUNG MEN TROUPE	L
26	Road	10	c/wh	LEGENDARY TRULY	U
27	Terminal	13	Lblu/blk	REMOTELY OUTER	R
28	Road	27	p/yg	MONDAY COURSE	U

†Color key: blk = black, c = coral, blu = blue, Lblu = light blue, o = orange, p = purple, r = red, y = yellow, yg = brilliant yellow-green, wh = white.

APPENDIX O. LIGHTING AND WEATHER CONDITIONS FOR STUDY 1

Notes:
1. All vertical readings were taken with light sensor held parallel to sign and perpendicular to ground.
2. All horizontal readings were taken with light sensor held perpendicular to sign and parallel to ground.
3. All measurements were taken from the Northeast end of the test strip, with the signs facing Southwest.

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
2-Jul-97	6:21 PM	72800	43700	clear w/light sky background
2-Jul-97	6:35 PM	68400	37300	clear w/light sky background
2-Jul-97	6:50 PM	67000	32700	clear w/light sky background
2-Jul-97	7:05 PM	64800	29400	clear w/light sky background
2-Jul-97	7:20 PM	50700	19800	clear w/light sky background
2-Jul-97	7:35 PM	44000	15600	clear w/light sky background
2-Jul-97	7:50 PM	29900	9700	clear w/light sky background
2-Jul-97	8:05 PM	20600	7100	clear w/light sky background

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
3-Jul-97	8:30 AM	7800	33300	sunny w/haze near ground in background
3-Jul-97	8:45 AM	8300	40400	sunny w/haze near ground in background
3-Jul-97	9:00 AM	8900	47000	sunny w/haze near ground in background
3-Jul-97	9:15 AM	9300	50000	sunny w/haze near ground in background
3-Jul-97	9:30 AM	9800	60500	sunny w/haze near ground in background
3-Jul-97	9:45 AM	11000	69000	sunny w/haze near ground in background

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
8-Jul-97	10:10 PM	0	0	clear sky with quarter moon

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
9-Jul-97	10:00 AM	12500	61600	sunny, hazy, partly cloudy
9-Jul-97	10:15 AM	14700	41400	sunny, hazy, partly cloudy
9-Jul-97	10:30 AM	15000	44400	sunny, hazy, partly cloudy
9-Jul-97	10:45 AM	14700	91800	sunny, hazy, partly cloudy
9-Jul-97	11:00 AM	12400	56900	sunny, hazy, partly cloudy
9-Jul-97	11:15 AM	13700	92000	sunny, hazy, partly cloudy

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
9-Jul-97	6:50 PM	2000	3440	cloudy, overcast
9-Jul-97	7:05 PM	1290	2010	cloudy, overcast

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
10-Jul-97	9:20 AM	12500	66000	mostly cloudy w/occasional sunshine
10-Jul-97	9:35 AM	14200	70800	mostly cloudy w/occasional sunshine
10-Jul-97	9:50 AM	14600	74900	mostly cloudy w/occasional sunshine
10-Jul-97	10:05 AM	16500	79800	mostly cloudy w/occasional sunshine
10-Jul-97	10:20 AM	12000	32600	mostly cloudy w/occasional sunshine
10-Jul-97	10:35 AM	21200	100000	mostly cloudy w/occasional sunshine
10-Jul-97	10:50 AM	16800	41200	mostly cloudy w/occasional sunshine

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
10-Jul-97	10:12 PM	0	0	clear sky with quarter moon

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
11-Jul-97	6:25 PM	37000	12600	mostly sunny
11-Jul-97	6:40 PM	16800	11800	mostly sunny
11-Jul-97	6:55 PM	18100	11400	mostly sunny
11-Jul-97	7:10 PM	44000	19400	mostly sunny
11-Jul-97	7:25 PM	36300	14600	mostly sunny
11-Jul-97	7:40 PM	33900	12500	mostly sunny
11-Jul-97	7:55 PM	22500	8400	mostly sunny

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
12-Jul-97	10:00 PM	0	0	clear sky with half moon

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
14-Jul-97	9:30 AM	9800	55800	sunny w/haze near ground in background
14-Jul-97	9:45 AM	9900	61000	sunny w/haze near ground in background
14-Jul-97	10:00 AM	10600	67900	sunny w/haze near ground in background
14-Jul-97	10:15 AM	11000	72400	sunny w/haze near ground in background
14-Jul-97	10:30 AM	11000	76000	sunny w/haze near ground in background
14-Jul-97	10:45 AM	11300	80300	sunny w/haze near ground in background

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
14-Jul-97	10:00 PM	0	0	partly cloudy sky with half moon

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
15-Jul-97	6:30 PM	39200	30600	mostly sunny
15-Jul-97	6:45 PM	35100	26700	mostly sunny
15-Jul-97	7:00 PM	34200	25700	mostly sunny
15-Jul-97	7:15 PM	26400	21000	mostly sunny
15-Jul-97	7:30 PM	17400	14500	mostly sunny
15-Jul-97	7:45 PM	9800	8600	mostly sunny

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
15-Jul-97	10:00 PM	0	0	clear sky with three-quarter moon

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
16-Jul-97	6:30 PM	8370	15100	cloudy, overcast
16-Jul-97	6:45 PM	7650	13140	cloudy, overcast
16-Jul-97	7:00 PM	7620	11740	cloudy, overcast
16-Jul-97	7:15 PM	8140	11590	cloudy, overcast
16-Jul-97	7:30 PM	11530	11440	cloudy, overcast
16-Jul-97	7:45 PM	9720	10650	cloudy, overcast

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
17-Jul-97	10:00 PM	0	0	clear sky with near full moon

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
19-Jul-97	10:00 PM	0	0	clear sky with near full moon

Date	Time	Vertical Luminance (lux)	Horizontal Luminance (lux)	Weather Condition
24-Jul-97	4:05 PM	22800	32100	mostly cloudy w/occasional sunshine
24-Jul-97	4:20 PM	23500	29100	mostly cloudy w/occasional sunshine
24-Jul-97	4:35 PM	11400	20600	mostly cloudy w/occasional sunshine
24-Jul-97	4:50 PM	8000	15700	mostly cloudy w/occasional sunshine
24-Jul-97	5:50 PM	24900	34100	mostly cloudy w/occasional sunshine

APPENDIX P. MEAN LEGIBILITY RESULTS FOR STUDY 1

Table P-1. Mean legibility distances (in m) for all Sign Color Combinations for Text Legends and Arrow Icons, assessment for all participants.

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	89.09	31.74	AB
Coral and Blue	75.58	36.72	D
Coral and White	63.18	31.95	EF
Light Blue and Black	85.44	29.49	BC
Light Blue and Blue	78.48	34.57	CD
Light Blue and Yellow	59.59	35.50	F
Orange and Black	78.56	33.25	CD
Purple and Black	67.53	28.44	E
Purple and White	77.23	31.56	D
Purple and Yellow	81.81	27.60	CD
Purple and Brilliant Yellow-Green	74.98	28.79	D
Red/White from Red, White, & Blue	65.71	26.44	EF
White/Blue from Red, White, & Blue	92.63	37.29	A
Brilliant Yellow-Green and Black	82.67	35.25	BCD

Table P-2. Mean legibility distances (in m) for all Sign Color Combinations for Arrow Icons Only, assessment for all participants.

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	112.5	38.69	A
Coral and Blue	102.63	43.33	AB
Coral and White	78.20	37.28	D
Light Blue and Black	106.17	33.21	AB
Light Blue and Blue	103.83	37.47	AB
Light Blue and Yellow	78.97	44.55	D
Orange and Black	103.57	37.86	AB
Purple and Black	85.43	27.03	CD
Purple and White	101.90	37.37	AB
Purple and Yellow	95.60	33.46	BC
Purple and Brilliant Yellow-Green	96.40	33.62	BC
White/Blue from Red, White, & Blue	111.69	38.17	A
Brilliant Yellow-Green and Black	111.53	40.00	A

Table P-3. Mean legibility distances (in m) for all Sign Color Combinations for Text Legends Only, assessment for all participants.

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	77.38	19.12	A
Coral and Blue	62.05	23.51	BC
Coral and White	55.67	26.17	D
Light Blue and Black	75.08	21.03	A
Light Blue and Blue	65.80	24.95	BC
Light Blue and Yellow	49.90	25.34	E
Orange and Black	66.05	22.04	BC
Purple and Black	58.58	24.83	CD
Purple and White	64.90	18.75	BC
Purple and Yellow	74.92	21.30	A
Purple and Brilliant Yellow-Green	64.27	18.58	BC
Red/White from Red, White, & Blue	65.71	26.44	BC
White/Blue from Red, White, & Blue	73.58	24.74	A
Brilliant Yellow-Green and Black	68.23	21.26	B

Table P-4. Mean legibility distances (in m) for all Sign Color Combinations for Text Legends with 100-mm Letter Height Only, assessment for all participants.

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	70.23	15.06	AB
Coral and Blue	51.17	20.63	FG
Coral and White	50.20	26.40	G
Light Blue and Black	66.43	14.40	ABC
Light Blue and Blue	52.30	20.73	EFG
Light Blue and Yellow	42.63	23.31	H
Orange and Black	55.93	19.34	DEFG
Purple and Black	42.70	20.04	H
Purple and White	58.33	16.51	DEF
Purple and Yellow	70.27	17.72	AB
Purple and Brilliant Yellow-Green	61.33	17.31	CD
Red/White from Red, White, & Blue	65.71	26.44	BC
White/Blue from Red, White, & Blue	73.58	24.74	A
Brilliant Yellow-Green and Black	59.23	18.18	CDE

Table P-5. Mean legibility distances (in m) for all Sign Color Combinations for Text Legends with 125-mm Letter Height Only, assessment for all participants.

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	84.53	20.28	A
Coral and Blue	72.93	21.30	CD
Coral and White	61.13	25.19	E
Light Blue and Black	83.73	23.19	AB
Light Blue and Blue	79.30	21.44	ABC
Light Blue and Yellow	57.17	25.58	E
Orange and Black	76.17	20.07	BC
Purple and Black	74.47	18.21	CD
Purple and White	71.67	18.81	CD
Purple and Yellow	79.57	23.75	ABC
Purple and Brilliant Yellow-Green	67.20	19.61	D
Brilliant Yellow-Green and Black	77.23	20.52	ABC

Table P-6. Mean legibility distances (in m) for all Sign Color Combinations for Text Legends with Series C Letters Only, assessment for all participants.

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	75.83	17.22	A
Coral and Blue	55.57	22.86	CD
Coral and White	50.20	24.57	DE
Light Blue and Black	70.20	14.85	AB
Light Blue and Blue	59.23	27.47	C
Light Blue and Yellow	44.93	23.07	E
Orange and Black	70.77	17.84	AB
Purple and Black	50.53	26.28	DE
Purple and White	67.30	18.98	B
Purple and Yellow	67.10	17.99	B
Purple and Brilliant Yellow-Green	58.93	17.65	C
Red/White from Red, White, & Blue	56.23	18.12	CD
White/Blue from Red, White, & Blue	58.60	13.69	C
Brilliant Yellow-Green and Black	63.53	16.20	BC

Table P-7. Mean legibility distances (in m) for all Sign Color Combinations for Text Legends with Series D Letters Only, assessment for all participants.

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	78.93	21.03	AB
Coral and Blue	68.53	22.68	CD
Coral and White	61.13	26.98	DE
Light Blue and Black	79.97	25.10	AB
Light Blue and Blue	72.37	20.56	BC
Light Blue and Yellow	54.87	26.90	E
Orange and Black	61.33	24.99	DE
Purple and Black	66.63	20.74	CD
Purple and White	62.50	18.53	DE
Purple and Yellow	82.73	21.74	A
Purple and Brilliant Yellow-Green	69.60	18.21	CD
Red/White from Red, White, & Blue	84.67	30.65	A
White/Blue from Red, White, & Blue	81.07	25.78	AB
Brilliant Yellow-Green and Black	72.93	24.72	BC

Table P-8. Mean legibility distances (in m) for all Sign Color Combinations for Text Legends with 100-mm Letter Height and Series C Letters Only, assessment for all participants.

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	72.60	14.67	A
Coral and Blue	42.27	17.41	D
Coral and White	42.13	22.33	D
Light Blue and Black	68.00	12.12	AB
Light Blue and Blue	42.53	21.52	D
Light Blue and Yellow	35.80	19.48	DE
Orange and Black	64.20	13.80	BC
Purple and Black	31.07	17.80	E
Purple and White	58.13	14.15	C
Purple and Yellow	63.00	16.83	BC
Purple and Brilliant Yellow-Green	55.40	15.72	C
Red/White from Red, White, & Blue	56.23	18.12	C
White/Blue from Red, White, & Blue	58.60	13.69	C
Brilliant Yellow-Green and Black	60.47	16.09	BC

Table P-9. Mean legibility distances (in m) for all Sign Color Combinations for Text Legends with 100-mm Letter Height and Series D Letters Only, assessment for all participants.

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	67.87	15.59	B
Coral and Blue	60.07	20.22	BCDE
Coral and White	58.27	28.39	BCDE
Light Blue and Black	64.87	16.66	BC
Light Blue and Blue	62.07	14.92	BCD
Light Blue and Yellow	49.47	25.42	DE
Orange and Black	47.67	20.94	E
Purple and Black	54.33	15.00	CDE
Purple and White	58.53	19.09	BCDE
Purple and Yellow	77.53	15.94	A
Purple and Brilliant Yellow-Green	67.27	17.26	BC
Red/White from Red, White, & Blue	84.67	30.65	A
White/Blue from Red, White, & Blue	81.07	25.78	A
Brilliant Yellow-Green and Black	58.00	20.56	BCDE

Table P-10. Mean legibility distances (in m) for all Sign Color combinations for Text Legends with 125-mm Letter Height and Series C Letters Only, assessment for all participants.

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	79.07	19.42	A
Coral and Blue	68.87	20.02	ABC
Coral and White	58.27	24.74	DE
Light Blue and Black	72.40	17.31	ABC
Light Blue and Blue	75.93	22.41	AB
Light Blue and Yellow	54.07	23.34	E
Orange and Black	77.33	19.40	AB
Purple and Black	70.00	17.37	ABC
Purple and White	76.47	19.12	AB
Purple and Yellow	71.20	18.74	ABC
Purple and Brilliant Yellow-Green	62.47	19.28	CDE
Brilliant Yellow-Green and Black	66.60	16.26	BCD

Table P-11. Mean legibility distances (in m) for all Sign Color Combinations for Text Legends with 125-mm Letter Height and Series D Letters Only, assessment for all participants.

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	90.00	20.26	AB
Coral and Blue	77.00	22.44	DE
Coral and White	64.00	26.17	GH
Light Blue and Black	95.07	23.22	A
Light Blue and Blue	82.67	20.64	BCD
Light Blue and Yellow	60.27	28.11	H
Orange and Black	75.00	21.33	DEF
Purple and Black	78.93	18.50	CDE
Purple and White	66.47	17.70	FGH
Purple and Yellow	87.93	25.82	ABC
Purple and Brilliant Yellow-Green	71.93	19.42	EFG
Brilliant Yellow-Green and Black	87.87	19.12	ABC

Table P-12. Mean legibility distances (in m) under Day viewing conditions for all sign color combinations with full text legends and arrow icons, assessment for all participants.

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	94.83	36.02	A
Coral and Blue	78.80	40.60	BCDE
Coral and White	72.56	27.78	DE
Light Blue and Black	90.30	32.01	AB
Light Blue and Blue	81.11	37.50	BCDE
Light Blue and Yellow	69.56	38.13	E
Orange and Black	83.57	37.23	BCD
Purple and Black	69.28	27.45	E
Purple and White	80.89	36.68	BCDE
Purple and Yellow	86.22	30.02	ABC
Purple and Brilliant Yellow-Green	77.43	32.06	CDE
Red/White from Red, White, & Blue	71.81	29.24	DE
White/Blue from Red, White, & Blue	96.15	43.66	A
Brilliant Yellow-Green and Black	89.00	38.45	ABC

Table P-13. Mean legibility distances (in m) under Night viewing conditions for all sign color combinations with full text legends and arrow icons, assessment for all participants.

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	80.47	21.66	B
Coral and Blue	70.75	29.88	BC
Coral and White	49.11	32.99	E
Light Blue and Black	78.17	23.86	B
Light Blue and Blue	74.53	29.73	BC
Light Blue and Yellow	44.64	25.01	E
Orange and Black	71.03	24.81	BC
Purple and Black	64.92	30.08	C
Purple and White	71.75	21.05	BC
Purple and Yellow	75.19	22.30	BC
Purple and Brilliant Yellow-Green	71.31	22.99	BC
Red/White from Red, White, & Blue	56.56	18.80	D
White/Blue from Red, White, & Blue	87.36	24.51	A
Brilliant Yellow-Green and Black	73.17	27.67	BC

Table P-14. Mean legibility distances (in m) for Younger and Older participants (except 42 year old male) for all sign color combinations (with text legends and arrow icons).

Color Combination	Legibility distance	STD	SNK Grouping
Coral and Black	87.76	31.58	AB
Coral and Blue	75.17	37.67	DE
Coral and White	60.71	31.49	F
Light Blue and Black	84.00	29.44	BC
Light Blue and Blue	76.67	33.48	CDE
Light Blue and Yellow	60.54	36.22	F
Orange and Black	78.17	33.91	CDE
Purple and Black	66.99	28.96	F
Purple and White	75.74	31.29	DE
Purple and Yellow	80.11	26.91	CDE
Purple and Brilliant Yellow-Green	73.26	28.25	E
Red/White from Red, White, & Blue	63.26	23.84	F
White/Blue from Red, White, & Blue	91.11	36.89	A
Brilliant Yellow-Green and Black	81.49	35.23	BCD

APPENDIX Q. ANALYSES OF VARIANCE FOR STUDY 1

Table Q-1. Analysis of variance table for legibility distance, all sign color combinations with text legends featuring *100-mm letter height*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	13	41155.29	3165.79	25.77	*0.0001
SGNCLR*SNUM	182	22358.12	122.85		
LTRSER	1	11081.59	11081.59	81.14	*0.0001
LTRSER*SNUM	14	1911.92	136.57		
LTRSER*SGNCLR	13	17963.87	1381.84	14.04	*0.0001
LTRSER*SGNCLR*SNUM	182	17916.45	98.44		
SNUM	14	105100.87	7507.21		
Total	419	217488.11			

*p < 0.05

Table Q-2. Analysis of variance table for legibility distance, all sign color combinations with text legends featuring *125-mm letter height*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	11	23461.21	2132.84	17.06	*0.0001
SGNCLR*SNUM	154	19258.42	125.05		
LTRSER	1	6820.81	6820.80	39.55	*0.0001
LTRSER*SNUM	14	2414.41	172.46		
LTRSER*SGNCLR	11	6853.63	623.06	7.08	*0.0001
LTRSER*SGNCLR*SNUM	154	13561.66	88.06		
SNUM	14	113750.85	8125.06		
Total	359	186120.99			

*p < 0.05

Table Q-3. Analysis of variance table for legibility distance, all sign color combinations with text legends featuring the *C letter series*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	13	30775.21	2367.32	21.01	*0.0001
SGNCLR*SNUM	182	20508.87	112.69		
LTRHGT	1	24272.04	24272.04	120.76	*0.0001
LTRHGT*SNUM	14	2813.87	200.99		
LTRHGT*SGNCLR	11	10658.82	968.98	14.76	*0.0001
LTRHGT*SGNCLR*SNUM	154	10109.26	65.64		
SNUM	14	90846.69	6489.05		
Total	389	189984.76			

*p < 0.05

Table Q-4. Analysis of variance table for legibility distance, all sign color combinations with text legends featuring the *D letter series*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	13	41259.19	3173.78	18.36	*0.0001
SGNCLR*SNUM	182	31463.34	172.88		
LTRHGT	1	27878.40	27878.40	127.78	*0.0001
LTRHGT*SNUM	14	3054.35	218.17		
LTRHGT*SGNCLR	11	7369.33	669.94	10.40	*0.0001
LTRHGT*SGNCLR*SNUM	154	9924.92	64.45		
SNUM	14	130298.47	9307.03		
Total	389	251248			

*p < 0.05

Table Q-5. Analysis of variance table for legibility distance, all sign color combinations with text legends featuring *100-mm letter height and C letter series*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	13	31281.12	2406.24	32.23	*0.0001
SGNCLR*SNUM	182	13586.71	74.65		
SNUM	14	43950.37	3139.31		
Total	209	88818.2			

*p < 0.05

Table Q-6. Analysis of variance table for legibility distance, all sign color combinations with text legends featuring *100-mm letter height and D letter series*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	13	28466.60	2189.74	15.57	*0.0001
SGNCLR*SNUM	182	25599.60	140.66		
SNUM	14	63062.43	4504.46		
Total	209	117128.63			

*p < 0.05

Table Q-7. Analysis of variance table for legibility distance, all sign color combinations with text legends featuring *125-mm letter height and C letter series*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	11	10152.91	922.99	8.35	*0.0001
SGNCLR*SNUM	154	17031.42	110.59		
SNUM	14	49716.44	3551.17		
Total	179	76900.77			

*p < 0.05

Table Q-8. Analysis of variance table for legibility distance, all sign color combinations with text legends featuring *125-mm letter height and D letter series*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	11	20161.93	1832.90	17.88	*0.0001
SGNCLR*SNUM	154	15788.66	102.52		
SNUM	14	66448.81	4746.34		
Total	179	102399.4			

*p < 0.05

Table Q-9. Analysis of variance table for legibility distance for test signs with *Coral background and Black legend*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRHGT	1	3067.35	3067.35	29.60	*0.0001
LTRHGT*SNUM	14	1450.90	103.64		
LTRSER	1	144.15	144.15	1.76	0.2063
LTRSER*SNUM	14	1149.10	82.08		
LTRHGT*LTRSER	1	920.42	920.42	14.93	*0.0017
LTRHGT*LTRSER*SNUM	14	862.83	61.63		
SNUM	14	13975.43	998.26		
Total	59	21570.18			

*p < 0.05

Table Q-10. Analysis of variance table for legibility distance for test signs with *Coral background and Blue legend*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRHGT	1	7106.82	7106.82	161.93	*0.0001
LTRHGT*SNUM	14	614.43	43.89		
LTRSER	1	2522.02	2522.02	31.21	*0.0001
LTRSER*SNUM	14	1131.23	80.80		
LTRHGT*LTRSER	1	350.42	350.42	4.37	0.0552
LTRHGT*LTRSER*SNUM	14	1121.83	80.13		
SNUM	14	19758.10	1411.29		
Total	59	32604.85			

*p < 0.05

Table Q-11. Analysis of variance table for legibility distance for test signs with *Coral background and White legend*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRHGT	1	1793.07	1793.07	30.92	*0.0001
LTRHGT*SNUM	14	811.93	57.99		
LTRSER	1	1793.07	1793.07	13.64	*0.0024
LTRSER*SNUM	14	1840.93	131.50		
LTRHGT*LTRSER	1	405.60	405.60	4.15	0.0609
LTRHGT*LTRSER*SNUM	14	1367.40	97.67		
SNUM	14	32399.33	2314.24		
Total	59	40411.33			

*p < 0.05

Table Q-12. Analysis of variance table for legibility distance for test signs with *Light Blue background and Black legend*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRHGT	1	4489.35	4489.35	50.94	*0.0001
LTRHGT*SNUM	14	1233.90	88.14		
LTRSER	1	1430.82	1430.82	20.90	*0.0004
LTRSER*SNUM	14	958.43	68.46		
LTRHGT*LTRSER	1	2496.15	2496.15	26.86	*0.0001
LTRHGT*LTRSER*SNUM	14	1301.10	92.94		
SNUM	14	14190.83	1013.63		
Total	59	26100.58			

*p < 0.05

Table Q-13. Analysis of variance table for legibility distance for test signs with *Light Blue background and Blue legend*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRHGT	1	10935.00	10935.00	99.31	*0.0001
LTRHGT*SNUM	14	1541.50	110.11		
LTRSER	1	2587.27	2587.27	42.96	*0.0001
LTRSER*SNUM	14	843.23	60.23		
LTRHGT*LTRSER	1	614.40	614.40	12.23	*0.0036
LTRHGT*LTRSER*SNUM	14	703.10	50.22		
SNUM	14	19507.10	1393.36		
Total	59	36731.6			

*p < 0.05

Table Q-14. Analysis of variance table for legibility distance for test signs with *Light Blue background and Yellow legend*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRHGT	1	3168.27	3168.27	39.23	*0.0001
LTRHGT*SNUM	14	1130.73	80.77		
LTRSER	1	1480.07	1480.07	5.37	*0.0361
LTRSER*SNUM	14	3856.93	275.50		
LTRHGT*LTRSER	1	209.07	209.07	1.79	0.2026
LTRHGT*LTRSER*SNUM	14	1637.93	116.99		
SNUM	14	26420.40	1887.17		
Total	59	37903.4			

*p < 0.05

Table Q-15. Analysis of variance table for legibility distance for test signs with *Orange background and Black legend*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRHGT	1	6140.82	6140.82	74.54	*0.0001
LTRHGT*SNUM	14	1153.43	82.39		
LTRSER	1	1334.82	1334.82	8.44	*0.0115
LTRSER*SNUM	14	2213.43	158.10		
LTRHGT*LTRSER	1	756.15	756.15	11.75	*0.0041
LTRHGT*LTRSER*SNUM	14	901.10	64.36		
SNUM	14	16171.10	1155.08		
Total	59	28670.85			

*p < 0.05

Table Q-16. Analysis of variance table for legibility distance for test signs with *Purple background and Black legend*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRHGT	1	15136.82	15136.82	175.51	*0.0001
LTRHGT*SNUM	14	1207.43	86.25		
LTRSER	1	3888.15	3888.15	83.09	*0.0001
LTRSER*SNUM	14	655.10	46.79		
LTRHGT*LTRSER	1	770.42	770.42	7.46	*0.0162
LTRHGT*LTRSER*SNUM	14	1445.83	103.27		
SNUM	14	13296.83	949.77		
Total	59	36400.58			

*p < 0.05

Table Q-17. Analysis of variance table for legibility distance for test signs with *Purple background and White legend*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRHGT	1	2587.27	2587.27	42.96	*0.0001
LTRHGT*SNUM	14	843.23	60.23		
LTRSER	1	345.60	345.60	5.91	*0.0291
LTRSER*SNUM	14	818.90	58.49		
LTRHGT*LTRSER	1	405.60	405.60	4.76	*0.0467
LTRHGT*LTRSER*SNUM	14	1193.90	85.28		
SNUM	14	14556.90	1039.78		
Total	59	20751.4			

*p < 0.05

Table Q-18. Analysis of variance table for legibility distance for test signs with *Purple background and Yellow legend*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRHGT	1	1297.35	1297.35	13.95	*0.0022
LTRHGT*SNUM	14	1301.90	92.99		
LTRSER	1	3666.02	3666.02	41.48	*0.0001
LTRSER*SNUM	14	1237.23	88.37		
LTRHGT*LTRSER	1	18.15	18.15	0.24	0.6336
LTRHGT*LTRSER*SNUM	14	1070.10	76.44		
SNUM	14	18165.83	1297.56		
Total	59	26756.58			

*p < 0.05

Table Q-19. Analysis of variance table for legibility distance for test signs with *Purple background and Brilliant Yellow-Green legend*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRHGT	1	516.27	516.27	10.74	*0.0055
LTRHGT*SNUM	14	672.73	48.05		
LTRSER	1	1706.67	1706.67	24.18	*0.0002
LTRSER*SNUM	14	988.33	70.60		
LTRHGT*LTRSER	1	21.60	21.60	0.50	0.4906
LTRHGT*LTRSER*SNUM	14	603.40	43.10		
SNUM	14	15848.73	1132.05		
Total	59	20357.73			

*p < 0.05

Table Q-20. Analysis of variance table for legibility distance for test signs with *Red legend on White background portion of the Red, White, and Blue* color scheme, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRSER	1	8084.54	8084.54	27.23	*0.0001
LTRSER*SNUM	14	4157.29	296.95		
SNUM	14	18467.07	1319.08		
Total	29	30708.9			

*p < 0.05

Table Q-21. Analysis of variance table for legibility distance for test signs with *White legend on Blue background portion of the Red, White, and Blue* color scheme, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRSER	1	5047.51	5047.51	26.79	*0.0001
LTRSER*SNUM	14	2637.49	188.39		
SNUM	14	10878.56	777.04		
Total	29	18563.56			

*p < 0.05

Table Q-22. Analysis of variance table for legibility distance for test signs with *Brilliant Yellow-Green background and Black legend*, assessment for all subjects.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LTRHGT	1	4860.00	4860.00	63.59	*0.0001
LTRHGT*SNUM	14	1070.00	76.43		
LTRSER	1	1325.40	1325.40	21.87	*0.0004
LTRSER*SNUM	14	848.60	60.61		
LTRHGT*LTRSER	1	2112.27	2112.27	44.69	*0.0001
LTRHGT*LTRSER*SNUM	14	661.73	47.27		
SNUM	14	15780.73	1127.20		
Total	59	26658.73			

*p < 0.05

Table Q-23. Analysis of variance table for legibility distance, all sign color combinations with full text and arrow legends, assessment under *Day* viewing conditions only.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	13	53667.76	4128.29	10.58	*0.0001
SGNCLR*SNUM	104	40594.82	390.33		
SNUM	8	334138.36	41767.29		
Total	125	428400.94			

*p < 0.05

Table Q-24. Analysis of variance table for legibility distance, all sign color combinations with full text and arrow legends, assessment under *Night* viewing conditions only.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	13	62496.87	4807.45	24.93	*0.0001
SGNCLR*SNUM	65	12536.98	192.88		
SNUM	5	134226.55	26845.31		
Total	83	209260.4			

*p < 0.05

Table Q-25. Analysis of variance table for subjective preference data, all sign color combinations, assessment under *Day* viewing conditions only.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	12	61.17	5.10	9.49	*0.0001
SGNCLR*SNUM	96	51.57	0.54		
SNUM	8	23.68	2.96		
Total	116	136.42			

*p < 0.05

Table Q-26. Analysis of variance table for subjective preference data, all sign color combinations, assessment under *Night* viewing conditions only.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	12	86.69	7.22	17.36	*0.0001
SGNCLR*SNUM	60	24.96	0.41		
SNUM	5	22.16	4.43		
Total	77	133.81			

*p < 0.05

APPENDIX R. PARTICIPANT INFORMATION FOR STUDY 2

Sign Color Combination	Visibility Condition	Gender (M/F)	Age (yrs)	Visual Acuity	Color Vision*
Orange w/ Black	Day	Male	21	20/22	Fail
Orange w/ Black	Day	Male	20	20/18	Mild Deficiency.
Orange w/ Black	Day	Female	34	20/15	Normal
Orange w/ Black	Day	Female	28	20/15	Mild Deficiency.
Orange w/ Black	Day	Male	23	20/13	Normal
Orange w/ Black	Night	Male	25	20/30	Fail
Orange w/ Black	Night	Female	29	20/18	MD
Orange w/ Black	Night	Female	21	20/15	Normal
Orange w/ Black	Night	Male	21	20/18	Normal
Orange w/ Black	Day	Female	71	20/40	Fail
Orange w/ Black	Day	Female	58	20/22	Fail
Orange w/ Black	Day	Female	69	20/30	Mild Deficiency.
Orange w/ Black	Day	Male	68	20/30	Fail
Orange w/ Black	Night	Male	66	20/40	Fail
Orange w/ Black	Night	Female	66	20/17	Fail
Purple w/ Yellow	Day	Male	20	20/30	Mild Deficiency.
Purple w/ Yellow	Day	Female	28	20/18	Mild Deficiency.
Purple w/ Yellow	Day	Female	18	20/40	Normal
Purple w/ Yellow	Day	Female	21	20/20	Mild Deficiency.
Purple w/ Yellow	Night	Female	24	20/30	Mild Deficiency.
Purple w/ Yellow	Night	Female	26	20/22	Mild Deficiency.
Purple w/ Yellow	Night	Male	22	20/20	Normal
Purple w/ Yellow	Night	Male	26	20/15	Mild Deficiency.
Purple w/ Yellow	Night	Female	25	20/40	Mild Deficiency.
Purple w/ Yellow	Night	Female	25	20/22	Mild Deficiency.
Purple w/ Yellow	Day	Female	58	20/40	Mild Deficiency.
Purple w/ Yellow	Day	Female	70	20/40	Fail
Purple w/ Yellow	Day	Female	63	20/35	Mild Deficiency.
Purple w/ Yellow	Day	Male	71	20/40	Fail
Purple w/ Yellow	Night	Female	60	20/35	Fail
Purple w/ Yellow	Night	Male	60	20/20	Mild Deficiency.
Purple w/ Yellow	Night	Female	66	20/22	Mild Deficiency.
Purple w/ Yellow	Night	Male	57	20/15	Mild Deficiency.
Purple w/ Yellow	Night	Female	58	20/18	Fail

Participant Information for Study 2 (continued).

Sign Color Combination	Visibility Condition	Gender (M/F)	Age (yrs)	Visual Acuity	Color Vision*
Light Blue w/ Black	Day	Female	31	20/20	Mild Deficiency.
Light Blue w/ Black	Day	Male	25	20/18	Fail
Light Blue w/ Black	Day	Female	26	20/15	Mild Deficiency.
Light Blue w/ Black	Day	Male	30	20/13	Mild Deficiency.
Light Blue w/ Black	Night	Female	30	20/25	Mild Deficiency.
Light Blue w/ Black	Night	Female	28	20/13	Mild Deficiency.
Light Blue w/ Black	Night	Male	30	20/15	Fail
Light Blue w/ Black	Night	Male	33	20/20	Mild Deficiency.
Light Blue w/ Black	Night	Male	29	20/15	Mild Deficiency.
Light Blue w/ Black	Day	Female	74	20/25	Fail
Light Blue w/ Black	Day	Male	63	20/25	Fail
Light Blue w/ Black	Day	Female	70	20/17	Fail
Light Blue w/ Black	Day	Female	65	20/40	Fail
Light Blue w/ Black	Day	Female	62	20/18	Fail
Light Blue w/ Black	Day	Female	75	20/25	Fail
Light Blue w/ Black	Night	Female	54	20/40	Mild Deficiency.
Light Blue w/ Black	Night	Male	55	20/18	Mild Deficiency.
Coral w/ Black	Day	Female	34	20/18	Mild Deficiency.
Coral w/ Black	Day	Female	29	20/25	Mild Deficiency.
Coral w/ Black	Day	Male	22	20/15	Fail
Coral w/ Black	Day	Female	20	20/15	Mild Deficiency.
Coral w/ Black	Day	Female	31	20/18	Mild Deficiency.
Coral w/ Black	Day	Female	23	20/20	Fail
Coral w/ Black	Night	Female	34	20/15	Mild Deficiency.
Coral w/ Black	Night	Female	24	20/13	Normal
Coral w/ Black	Night	Male	33	20/17	Normal
Coral w/ Black	Night	Male	33	20/15	Fail
Coral w/ Black	Night	Male	33	20/18	Fail
Coral w/ Black	Day	Female	69	20/13	Fail
Coral w/ Black	Day	Male	58	20/20	Fail
Coral w/ Black	Day	Male	74	20/40	Fail
Coral w/ Black	Day	Female	71	20/35	Fail
Coral w/ Black	Day	Male	59	20/30	Mild Deficiency.
Coral w/ Black	Day	Female	57	20/17	Mild Deficiency.
Coral w/ Black	Night	Female	70	20/25	Fail
Coral w/ Black	Night	Female	66	20/40	Fail

APPENDIX S. DESCRIPTION AND MAP OF TEST AREA USED IN STUDY 2

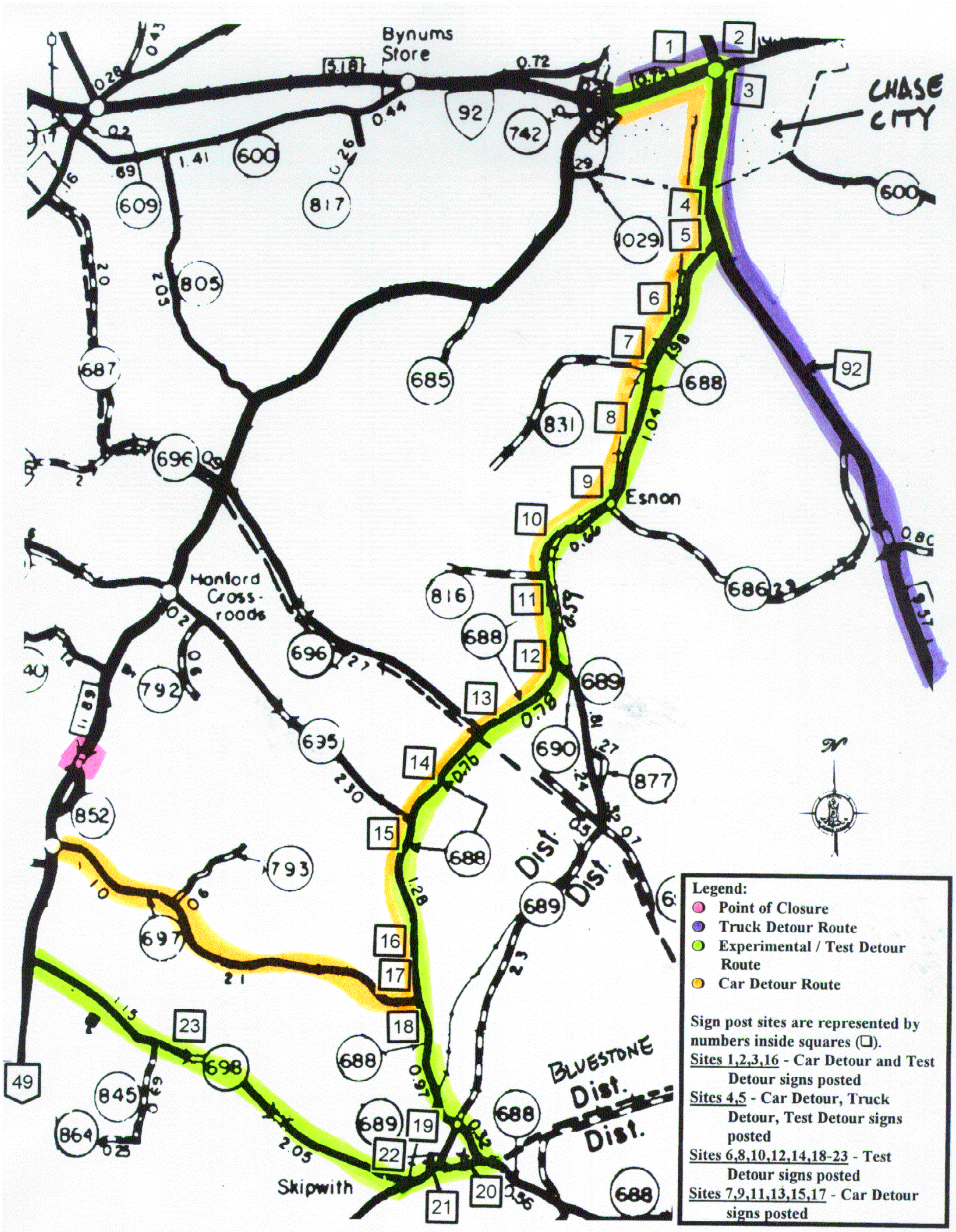


Figure S-1. Map of Test Route for Study 2.

Test signs were placed so as to match the density of existing detour signs, thus, the number of test signs matched the number of existing detour signs per unit of distance. Test signs placed at sites 1, 2, 3, 4, 5, and 16 were mounted on the same post as the existing detour signs. Signs placed at the remaining sites were either Detour or Test Detour signs. The remaining 4.5 miles of the test route employed only Test Detour signs.

Description of Experimental Route and Sign Postings.

Sign Post #	Description of Location	Detour, Test Detour, or Both w/ Direction
1*	In Chase City - 4-way intersection (with traffic lights) of routes 92 and 47/49. Signs indicate right turn onto North Main Street. Signs mounted on same post.	Right Detour Right Test Detour
2*	In Chase City - 3-way intersection of Rte. 92/North Main and Rte. 92/East Sycamore. Rte. 92/North Main traffic yields to Rte. 92/East Sycamore traffic. Signs indicate left turn onto Rte. 92/East Sycamore Street. Signs mounted on same post.	Left Detour Left Test Detour
3*	In Chase City - 3-way intersection of Rte. 92/East Sycamore Street and Rte. 92/South Main Street. Rte. 92/East Sycamore traffic yields to Rte. 92/South Main traffic. Signs indicate right turn onto Rte. 92/South Main Street. Signs mounted on same post.	Right Detour Right Test Detour
4	On Rte. 92 - advance detour warning. Car detour turns right onto State road 688 (Skipwith Road) to meet Rte. 49. Truck detour continues down Rte. 92. Signs mounted on same post.	Right Detour/Car Right Test Detour/Car Forward Detour/Truck
5	On Rte. 92 - signs prior to 3-way intersection of Rte. 92 and 688 (Skipwith Rd). Car detour signs indicate right turn onto 688 (Skipwith Rd). Signs mounted on same post.	Right Detour/Car Right Test Detour/Car Forward Detour/Truck
6	On 688 (Skipwith Rd) - 0.5 mi down 688 from Rte. 92.	Forward Test Detour
7	On 688 (Skipwith Rd) - at State road 831.	Forward Detour
8	On 688 (Skipwith Rd) - 0.5 mi past State road 831.	Forward Test Detour
9	On 688 (Skipwith Rd) - at State road 686 (Emon Rd).	Forward Detour
10	On 688 (Skipwith Rd) - 0.5 mi past State road 686, pass over railroad tracks immediate prior to passing test sign.	Forward Test Detour
11	On 688 (Skipwith Rd) - at State road 816.	Forward Detour
12	On 688 (Skipwith Rd) - at State road 689.	Forward Test Detour

*Signs posted in Chase City represent urban environment. All other signs posted in rural environment.

Description of Experimental Route and Sign Postings (continued).

Sign Post #	Description of Location	Detour, Test Detour, or Both w/ Direction
13	On 688 (Skipwith Rd) - at State road 696.	Forward Detour
14	On 688 (Skipwith Rd) - 0.4 past State road 696.	Forward Test Detour
15	On 688 (Skipwith Rd) - at State road 695, test sign is mounted below speed limit sign.	Forward Detour
16	On 688 (Skipwith Rd) - advance sign for existing car detour, existing sign indicates right turn onto State road 697 (Parkside Road). Test route continues past 697 (Parkside Rd). Signs mounted on same post. This site is located in a school zone, with school located at this intersection.	Right Detour Forward Test Detour
17	On 688 (Skipwith Rd) - at State road 697 (Parkside Rd), existing car detour indicates right turn onto 697 (Parkside Rd).	Right Detour
18	On 688 (Skipwith Rd) - after State road 697 (Parkside Rd). Second test sign to assist drivers.	Forward Test Detour
19	On 688 (Skipwith Rd) - at State road 689 (Rocky Mount Road), must pass over railroad tracks immediately prior to sign. Sign mounted below truck detour signs.	Forward Test Detour
20	On 688 (Skipwith Rd) - at State road 701 (Wilbourne Road), test signs indicate right turn onto 701 (Wilbourne Road). No advance sign, and road bends to left immediately prior to sign. Sign mounted above speed limit sign.	Right Test Detour
21	On 701 (Wilbourne Rd) - at 3-way intersection of 701 (Wilbourne Rd) and 689 (Rocky Mount Rd). Rte 701 (Wilbourne Rd) traffic must stop and yield to 701/689 traffic. Test sign indicates left turn, continuing with 701 (Wilbourne Rd).	Left Test Detour
22a	On 701 (Wilbourne Rd) - advance sign for right turn onto State Road 698 (Middle School Rd).	Right Test Detour
22b	On 701 (Wilbourne Rd) - at 698 (Middle School Rd), must pass over railroad tracks immediately prior to sign. Sign indicates right turn onto 698 (Middle School Rd).	Right Test Detour
23	On 698 (Middle School Rd) - at State road 845.	Forward Test Detour

Figure S-2. Sample sign posting – overlaid detours.

Figure S-3. Sample sign posting – single detour sign.

The above photos provide examples of how the test detour signs were placed along the route. The photo shown in Figure S-2 was taken at a location where the experimental detour, car detour, and truck detour overlap, thus requiring the corresponding detour signs to be “overlaid.” The photo shown in Figure S-3 is representative of a location where only one detour sign, experimental/test or car detour, was posted.

APPENDIX T. 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 (in). 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.

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.

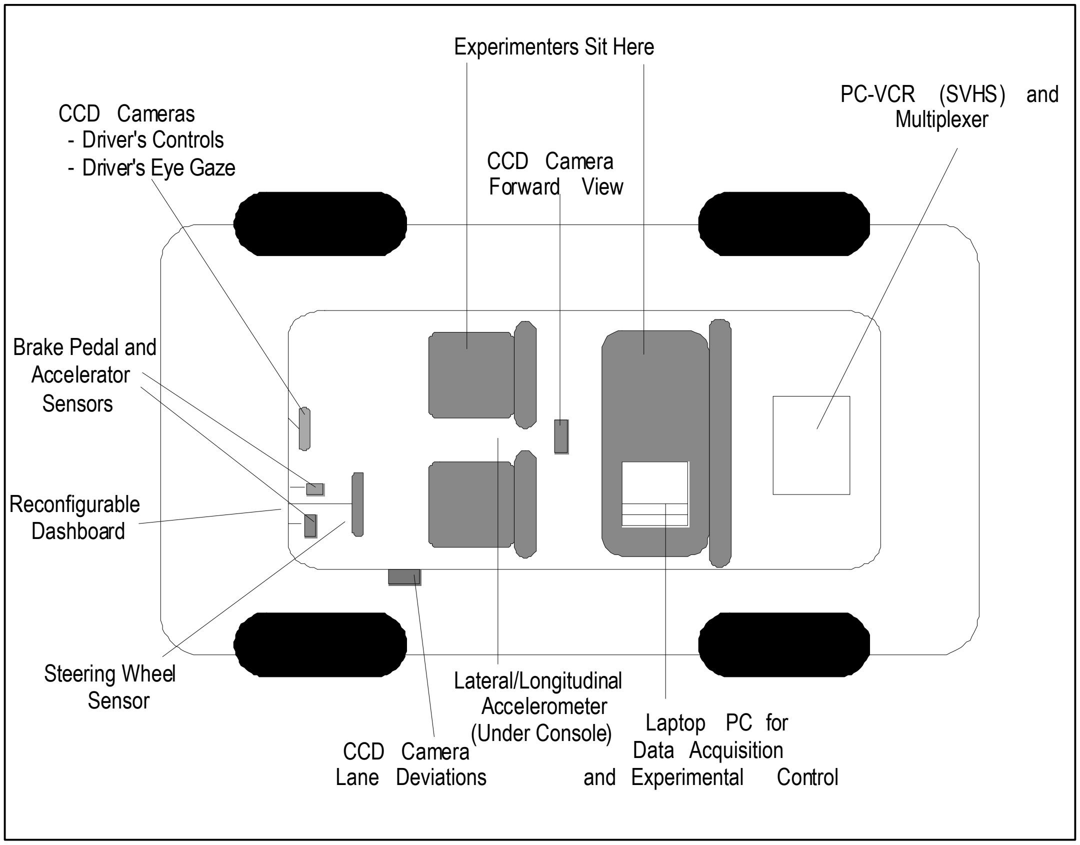


Figure T-1. Diagram of the instrumented vehicle.

APPENDIX U. POST-TEST QUESTIONNAIRE FOR STUDY 2

VIRGINIA TECH CENTER FOR TRANSPORTATION RESEARCH
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 detour 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: ___________

4. Please answer the following questions using the sign samples shown on the following pages.

> *Example. Suppose you are shown the following sign sample colors:*
> *1) red and white, 2) green and yellow, and 3) brown and blue.*
> *Rank in order of preference:*
>
> | | |
> |---|---|
> | *Most preferred* | *brown and blue* |
> | *Somewhat Preferred* | *red and white* |
> | *Least Preferred* | *green and yellow* |

Please use the color definitions provided with the sign samples.

a. 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 ________________________________

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

Most readable ________________________________
More readable ________________________________
Somewhat readable ________________________________
Least readable ________________________________

c. 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 V. INITIAL CONTACT AND SCREENING FORMS FOR STUDY 2

VIRGINIA TECH CENTER FOR TRANSPORTATION RESEARCH
SIGN CONSPICUITY STUDY
INITIAL CONTACT SCRIPT (BY PHONE OR IN PERSON)

INTERVIEWER:*I am conducting an on-the-road study of traffic signs for my graduate research at Virginia Tech. The purpose of this research project is to evaluate traffic signs of varying colors and design parameters to determine which signs produce the greatest visibility distance during day and night conditions on dry pavement, as well to evaluate driver behavior relative to use of these signs.*

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 and perform a test drive of the experimental vehicle until you are comfortable with the vehicle and the tasks that you will perform as part of this experiment.*
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. The total experiment time will be approximately 1 hour.

Would you be interested in participating?

POTENTIAL PARTICIPANT: YES or NO

INTERVIEWER:*As part of the experiment, I need to ask you a few questions. Your answers will help me determine if I can include you as a participant in my study and if so, it will also help me group and sort the data from the study. This data will not be associated with your name, and will be treated confidentially*.

See following pages.

VIRGINIA TECH CENTER FOR TRANSPORTATION RESEARCH
SIGN CONSPICUITY STUDY

INITIAL CONTACT SCREENING QUESTIONNAIRE AND
BACKGROUND INFORMATION (BY PHONE)

Participant's Name:____Date of Birth:_________________
Participant's Phone No.:______________________ Gender: M or F
Eligibility Status:_____________________ Date and Time:______________________

For office use:	**Participant ID: ________**

NOTE TO INTERVIEWER: The initial screening consists of two parts: 1) demographic information and 2) health screening. Ask the participant the following questions and record his/her responses. If the participant does not have a valid driver's license, thank the person for his/her time and explain that this criteria must be met in order to participate. If the participant reveals a health condition which disqualifies him/her from safe participation in this study, thank the person for his/her time and explain that he/she is not eligible to participate for safety reasons.

PHONE INTERVIEWER: *As part of the study, I need to ask you a few questions. Your answers will determine your eligibility for this study. This data will not be associated with your name, and will be treated confidentially*.

1) To participate, you need to have a valid driver's license. Do you have a valid license?

YES NO

2) How many times per week do you drive?

4+ 2-3X 1X <1X

3) Approximately how many miles do you drive per year?

1 ❑ Under 2,000
2 ❑ 2,000 - 7,999
3 ❑ 8,000 - 12,999
4 ❑ 13,000 - 19,999
5 ❑ 20,000 or more

PHONE INTERVIEWER: If participant is eligible, then conduct the health screening.

See following pages.

VIRGINIA TECH CENTER FOR TRANSPORTATION RESEARCH
SIGN CONSPICUITY STUDY
Health Screening Questionnaire - Part I

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 recently.
   ____
   ____

2. Have you experienced any of the following conditions on a regular basis?

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.
   ____
   ____

VIRGINIA TECH CENTER FOR TRANSPORTATION RESEARCH
SIGN CONSPICUITY STUDY

INITIAL CONTACT SCREENING QUESTIONNAIRE AND
BACKGROUND INFORMATION (CONT'D)

Participant ID: ________

PHONE INTERVIEWER: If participant is eligible based on results of background information and health screening...*Now I'd like to schedule a time when you can come out to the field laboratory for the study*. If participant is not eligible based on results of health screening...*Thank you for your time; unfortunately you are not eligible for this particular study due to safety considerations. Would you be interested on being put on a participant list for future studies?*

A. Schedule a time DATE AND TIME:_________________________________

PHONE INTERVIEWER: If participant is eligible based on results of background information and health screening...*Do you have transportation to the field laboratory, or do you need transportation. We can arrange for someone to pick you up and return you home afterwards*. If yes...*Please you give me directions to the place where we will pick you up.*

____

____

PHONE INTERVIEWER: *Also, please refrain from drinking alcohol for the 24 hours before the experiment. Is this all right with you?* YES__________NO___________

PHONE INTERVIEWER: *I will call to remind you of when the experiment is scheduled. This reminder will occur approximately 24 hours before your appointment. At that time I will also include directions to the field laboratory if necessary. Thank you! I'll see you* <insert date and time>.

comments:
____
____
____
____

Time Preference: DAY NIGHT

VIRGINIA TECH CENTER FOR TRANSPORTATION RESEARCH
SIGN CONSPICUITY STUDY

Health Screening Questionnaire - Part II

Participant ID: ________

NOTE TO INTERVIEWER: This is a part 2 of a two-part questionnaire. This part must be completed and signed immediately prior to participation in the study.

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

   ____
   ____
   ____

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

   ____
   ____

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

   ____
   ____

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

   Yes No

______________________________ ______________________________
Signature Date

APPENDIX W. INFORMED CONSENT FORM FOR STUDY 2

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

Title of the Project: <u>On-Road Evaluation of Sign Design Parameters to Determine Improvements of Conspicuity for Traffic Signs</u>
Investigators: <u>Julie A. Barker, Dr. Vicki L. Neale, and Dr. Thomas A. Dingus</u>

I. THE PURPOSE OF THIS RESEARCH

The purpose of this research project is to evaluate how drivers perform when navigating a route. Participants will drive an instrumented vehicle along a predetermined route in a normal traffic situation, and will follow the directional information provided by 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 and conspicuous traffic control devices. 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 and perform a test drive of the experimental vehicle until you are comfortable with the vehicle and the tasks that you will perform as part of this experiment.
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 navigation devices provided 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 1 hour.

It is important for you to understand that we are evaluating the navigation materials, not you. Therefore, we ask that you perform to the best of your abilities. If you ever feel frustrated in attempting complete the task, 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. However, you will be given rest breaks during the experimental session.
(3) While you are driving the vehicle, you will be videotaped by cameras. Due to this fact, we will ask that you not wear sunglasses. If this at any time during the course of the experiment impairs your ability to drive the vehicle safely, you should to notify the experimenter.

The following precautions will be taken to ensure minimal risk to the you.

(1) An experimenter will monitor your driving and will ask you to stop if she feels the risks are too great to continue. However, as long as the you are driving the research vehicle, it remains you responsibility to drive in a safe, legal manner.
(2) You are 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 the test participant fails to brake.
(4) The vehicle is equipped with a fire extinguisher, first-aid kit, and a cellular phone, which may be used in an emergency.
(5) If an accident does occur, the experimenters will arrange medical transportation to a nearby hospital emergency room. In that event, 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, the driver, 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 control devices composed of various design parameters and colors. This may have a significant impact on highway traffic sign effectiveness, as well as on driving safety, when these color combinations and design parameters are employed. 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 $25.00 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 <u>free to withdraw at any time</u> 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 Center for Transportation Research.

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:

Julie A. Barker, Investigator	(540) 961-7441
Vicki L. Neale, Project Manager	(540) 231-5578
Thomas A. Dingus, Principal Investigator	(540) 231-8831
H. T. Hurd, Chair, IRB	(540) 231-5281

APPENDIX X. SCRIPTS OF TEST INSTRUCTIONS FOR STUDY 2

Center for Transportation Research Virginia Tech
Sign Conspicuity Study

Experimenter's Instructions Script

1. INTRODUCTIONS and INSTRUCTIONS

A. Greet Participant

B. Informed Consent Form

- *Give participant a copy of the informed consent form to read.*
- *Answer any general questions the participant might have about the study.*
- *Have participant sign and date the informed consent form.*
- *Give participant a copy of the informed consent form.*

C. Verify Driver's License

- *Have participant show a valid driver's license.*

D. Health, Medication, and Drug Questionnaire

- *Give participant a copy of the health, medication, and drug questionnaire to complete.*
- *Have participant sign and date the health, medication, and drug questionnaire.*
- *Review questionnaire to ensure that participant is fit to take part in the study.*

E. Vision Test and Color Vision Test

EXPERIMENTER: "Before we go out to the vehicle, I need to give you a vision test. This is a requirement of all participants of this study."

- *Administer vision test and color vision test per instructions provided by Vision and Color Tests' Scripts.*
- *Review results of both tests to ensure that participant is fit to take part in the study.*
- *If passes (at least 20/40 and meets required level of color vision), then go out to vehicle and continue with study. If fails, pay for time and excuse from study.*

2. ORIENTATION SESSION

A. Initial Briefing

EXPERIMENTER: "Do you have any questions at this point in time?"

- *Answer any general questions the participant might have.*

EXPERIMENTER: "Before we proceed, I would like to tell you that I will be reading from a script during much of our time together. This ensures that I will not forget to tell you anything. So, if I sound extremely formal at times, please understand that this is a requirement of the study."

"In order to make the experiment as objective and safe as possible, I'd like to go over a few points before we start driving."

"First, we will be driving over a predetermined and marked course. This course will be in the Mecklenburg County area. The course is marked by signs that say "TEST DETOUR" and a directional arrow. These signs will indicate your direction of travel."

B. Task Training

EXPERIMENTER: "Your task is to follow the test signs until the experimenter has indicated that you have reached the final destination. The experimenter will not be allowed to provide you with any other directional information."

"Do you have any questions?"

- *Answer any general questions the participant might have.*

C. Vehicle Briefing

- *Open front passenger side door for the participant and have him or her get into the front passenger seat.*
- *Get into front driver's side seat.*

EXPERIMENTER: "Before we begin today, I would like to take a few moments to familiarize you with this vehicle."

"Since the controls in this car may be different from those in your car, I would like to give you a chance to familiarize yourself with the controls. When I point out the location of each, please operate it."

- *Say name of each control and have subject operate it.*

EXPERIMENTER and PARTICIPANT:

1. WINDSHIELD WIPERS
2. LIGHTS
3. HORN
4. TURN SIGNALS
5. DEFOGGER
6. DEFROSTER

"Please note that, for your safety, this car is equipped with ABS brakes and driver's side and passenger's side airbags. Are you aware of these technologies?"

- *If not, explain.*

"In addition, and again for safety, I [the researcher riding in the front passenger's seat] will have access to an emergency brake that she will use in case of emergency. Do you have any questions about this safety feature?"

- *Answer general questions.*

EXPERIMENTER: "Now, I would like you to adjust the seat and steering wheel so that you are in a comfortable driving position. Make sure that you can see the entire instrument panel through the steering wheel. Please fasten your seatbelt and turn on your headlights.

- *Show seat adjustments and have the participant adjust the seat and steering wheel. Then have him/her fasten his/her seatbelt and turn on headlights (kept on for duration of experiment).*

EXPERIMENTER: "Now, please adjust the side- and rear-view mirrors to your liking."

- Have the participant adjust the side- and rear-view mirrors.
- Make sure the following system settings are achieved:
    1. Connect all computer cables.
    2. Power on display computer
    3. Power up data collection computer
    4. Load video cassette.

- Have subject start up the vehicle.

3. PRACTICE SESSION

EXPERIMENTER: "Now we will begin a practice drive to help you get familiar with operating the vehicle. During this drive, no TEST DETOUR signs will be located along the route.

- *Drive around the block. If subject feels comfortable with operating the car, then move on to the test route. If not comfortable, repeat the drive.*

4. TEST DRIVE

EXPERIMENTER: "During your upcoming drive, you will be driving on a predetermined route that is marked by a series of TEST DETOUR signs."

"Your task is to drive the vehicle in a safe manner, obeying all traffic laws. Your primary responsibility is to safely operate the vehicle. Other responsibilities are: Follow the directional information provided by all TEST DETOUR signs; follow the directions of all safety advisory and warning signs. There are no other tasks associated with this study."

"Do you have any questions about these tasks? Please note that I will not be allowed to answer questions while the drive is ongoing. Also, I will not be allowed to talk with you during the drive other than to tell you when the test drive has been completed."

- *Answer general questions.*

"Are you ready to begin the test drive?"

Data Collection

- *Begin preparing data collection equipment.*
    1. *Enter subject number.*
    2. *Enter gender.*
    3. *Enter color blindness flag.*
    4. *Enter input condition, i.e., sign number.*
    5. *Begin data collection.*

5. POST-TEST, DEBRIEFING, AND PAYMENT

- *Return to the field laboratory meeting place.*
- *Administer the User Survey.*
- *Answer any questions the participant has during the debriefing or about the study in general.*
- *Pay participant. Make sure that both you and the participant sign/date the payment log sheet.*
- *Thank participant for taking part in the study*

Experimenter Protocol

Tasks

The experimenter that rides in the passenger seat has three primary tasks. They are as follows:

1. Operate the safety brake -- to be used only in case of emergency. The emergency brake is a foot brake located in the front passenger's area.

2. Flag data--of unplanned events. A cord with a button attached must be held by the experimenter through the duration of the experiment. When a planned or unplanned event occurs, press down on the button holding it down for the duration of the event. When the even is over, release the button. The will place a "flag" in the data for observation at a later time. Flag any events where the driver is required to react (or should react and neglects to). Unplanned events are naturally occurring events that happen during the drive. Examples of unplanned events include a car braking sharply in front of the participant, a dog running across the road, a car merging towards the participant, a car traveling in the opposite direction slowing in an intersection and initiating a left turn, etc.

   In the case of multiple events, or when a second event begins before the first event ends, press the button for the first event, then again for the second even though the first hasn't finished yet.

3. Provide direction information to the subject--during the drive. The experimenter must have a thorough understanding of the route and all turns. Information is provided when beginning the test route and when noting the end of the test run.

APPENDIX Y. LIGHTING AND WEATHER CONDITIONS FOR STUDY 2

Notes:
1. All horizontal readings were taken with light sensor held parallel to ground.
2. All measures taken on the open sidewalk outside of the field lab meeting place, the Chase City Police Department in Chase City, Virginia.

Sign configuration #1: Orange and Black color combinations.

Date	Time	Luminance (lux)	Weather Condition
14-Aug-97	9:55 AM	58000	sunny
14-Aug-97	10:30 AM	82600	sunny
14-Aug-97	11:30 AM	95900	sunny
15-Aug-97	11:00 AM	19200	cloudy, overcast
16-Aug-97	9:00 PM	4	almost full moon, clear skies
17-Aug-97	8:50 PM	4	full moon, clear skies
17-Aug-97	9:50 PM	4	full moon, clear skies
18-Aug-97	9:00 AM	50100	variably cloudy
18-Aug-97	10:15 AM	26800	variably cloudy, overcast
18-Aug-97	8:35 PM	6	full moon, partly cloudy skies
19-Aug-97	9:05 AM	39500	sunny and hazy
19-Aug-97	10:15 AM	61500	sunny and hazy
19-Aug-97	1:30 PM	81200	sunny, partly cloudy
19-Aug-97	10:20 PM	4	full moon, clear skies
19-Aug-97	11:00 PM	4	full moon, clear skies

Sign configuration #2: Purple and Yellow color combinations.

Date	Time	Luminance (lux)	Weather Condition
21-Aug-97	9:20 PM	4	clear skies
21-Aug-97	10:15 PM	3	clear skies
21-Aug-97	10:30 PM	3	clear skies
22-Aug-97	10:10 AM	70200	sunny, partly cloudy
22-Aug-97	11:10 AM	90500	sunny, partly cloudy
22-Aug-97	9:05 PM	4	clear skies
23-Aug-97	8:30 PM	3	clear skies
24-Aug-97	2:10 PM	22800	partly cloudy
24-Aug-97	8:30 PM	4	clear skies
24-Aug-97	9:30 PM	4	clear skies
25-Aug-97	11:25 AM	85200	sunny, partly cloudy
25-Aug-97	5:30 PM	40900	sunny, clear skies
25-Aug-97	8:15 PM	5	clear skies
25-Aug-97	9:30 PM	4	clear skies
26-Aug-97	10:45 AM	74000	sunny, clear skies
26-Aug-97	4:40 PM	55500	sunny
26-Aug-97	8:15 PM	5	clear skies
27-Aug-97	4:30 PM	55400	sunny
27-Aug-97	8:15 PM	5	clear skies

Sign configuration #3: Light Blue and Black color combinations.

Date	Time	Luminance (lux)	Weather Condition
28-Aug-97	9:30 PM	3	
29-Aug-97	11:35 AM	24800	partly cloudy
29-Aug-97	1:15 PM	95300	sunny, partly cloudy
29-Aug-97	2:30 PM	88200	sunny, partly cloudy
29-Aug-97	3:15 PM	78500	sunny, partly cloudy
29-Aug-97	4:10 PM	76700	sunny, partly cloudy
29-Aug-97	8:30 PM	4	
2-Sep-97	11:10 AM	78200	sunny
2-Sep-97	12:30 PM	85900	sunny
2-Sep-97	8:50 PM	5	
3-Sep-97	9:05 AM	17100	sunny, partly cloudy
3-Sep-97	11:00 AM	40300	mostly cloudy
3-Sep-97	8:05 PM	7	clear skies
3-Sep-97	9:00 PM	4	clear skies
4-Sep-97	8:55 AM	35500	sunny, clear skies
4-Sep-97	9:00 PM	4	clear skies
4-Sep-97	10:00 PM	4	clear skies

Sign configuration #4: Coral and Black color combinations.

Date	Time	Luminance (lux)	Weather Condition
5-Sep-97	8:30 PM	4	clear skies
6-Sep-97	11:00 AM		partly cloudy, overcast
6-Sep-97	12:00 PM	86800	partly cloudy, overcast
6-Sep-97	1:00 PM	102300	partly cloudy, overcast
6-Sep-97	8:30 PM	4	clear skies
6-Sep-97	9:30 PM	4	
7-Sep-97	12:00 PM	86600	sunny, partly cloudy
7-Sep-97	2:00 PM		sunny
7-Sep-97	3:00 PM		sunny
7-Sep-97	8:45 PM	4	quarter moon, clear skies
8-Sep-97	10:00 AM	52000	sunny, partly cloudy
8-Sep-97	12:00 PM	86000	sunny, partly cloudy
8-Sep-97	1:10 PM	10400	mostly cloudy
8-Sep-97	2:30 PM		mostly cloudy
8-Sep-97	3:30 PM	60900	sunny, partly cloudy
8-Sep-97	4:30 PM	54500	sunny, partly cloudy
8-Sep-97	8:00 PM	4	quarter moon, clear skies
8-Sep-97	9:00 PM	4	quarter moon, clear skies
8-Sep-97	10:00 PM	4	quarter moon, clear skies

APPENDIX Z. STATISTICAL TABLES FOR STUDY 2 SURVEY QUESTIONS

Significant *p*, *z* or χ^2 values are indicated by an asterisk in the right hand column.

Table Z-1. Statistical results for pairwise comparisons for late braking maneuvers, assessment by sign color.

Sign Color Background	Significance Level
Orange vs Purple	χ^2(1, N=34) = 1.454, p = 0.228*
Orange vs Light Blue	χ^2(1, N=32) = 1.091, p = 0.296*
Orange vs Coral	χ^2(1, N=34) = 0.045, p = 0.832
Purple vs Light Blue	χ^2(1, N=36) = 0.000, p = 1.000*
Purple vs Coral	χ^2(1, N=38) = 2.330, p = 0.127*
Light Blue vs Coral	χ^2(1, N=36) = 1.820, p = 0.177*

*Statistic is adjusted to account for expected frequency counts less than 5.

Table Z-2. Statistical results for pairwise comparisons for frequency of turn errors, assessment by sign color.

Sign Color Background	Significance Level
Orange vs Purple	χ^2(1, N=782) = 1.565, p = 0.211
Orange vs Light Blue	χ^2(1, N=736) = 8.279, p = 0.004*
Orange vs Coral	χ^2(1, N=782) = 1.565, p = 0.211
Purple vs Light Blue	χ^2(1, N=828) = 3.667, p = 0.055*
Purple vs Coral	χ^2(1, N=874) = 0.000, p = 1.000
Light Blue vs Coral	χ^2(1, N=828) = 3.667, p = 0.055*

*Statistic is adjusted to account for expected frequency counts less than 5.

Table Z-3. Statistical results for pairwise comparisons for frequency of turn errors for daytime drivers.

Sign Color Background	Significance Level
Orange vs Purple	i^2(1,N=391) = 1.190, p = 0.275*
Orange vs Light Blue	i^2(1,N=437) = 3.687, p = 0.055*
Orange vs Coral	i^2(1,N=483) = 2.563, p = 0.109*
Purple vs Light Blue	i^2(1,N=414) = 0.013, p = 0.911*
Purple vs Coral	i^2(1,N=460) = 0.000, p = 1.000*
Light Blue vs Coral	i^2(1,N=506) = 0.000, p = 1.000*

*Statistic is adjusted to account for expected frequency counts less than 5.

Table Z-4. Analysis of variance table for survey question #1.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	3	2.69	0.90	1.55	0.2121
AGE	1	1.03	1.03	1.78	0.1879
VISCON	1	6.49	6.49	11.23	0.0015*
SGNCLR*AGE	3	3.32	1.11	1.91	0.1384
SGNCLR*VISCON	3	0.72	0.24	0.41	0.7438
VISCON*AGE	1	0.08	0.08	0.14	0.7107
SGNCLR*AGE*VISCON	3	0.55	0.18	0.32	0.8129
SNUM(SGNCLR, AGE, VISCON)	54	31.22	0.58		
Total	69	46.1			

*p<0.05

Table Z-5. Analysis of variance table for survey question #2.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	3	1.87	0.62	1.11	0.3532
AGE	1	0.81	0.80	1.44	0.2361
VISCON	1	12.53	12.53	22.47	0.0001*
SGNCLR*AGE	3	1.56	0.52	0.93	0.4320
SGNCLR*VISCON	3	3.3	1.11	1.98	0.1277
VISCON*AGE	1	0.25	0.25	0.46	0.5024
SGNCLR*AGE*VISCON	3	0.83	0.28	0.50	0.6863
SNUM(SGNCLR, AGE, VISCON)	54	30.12	0.56		
Total	69	51.27			

*p<0.05

Table Z-6. Analysis of variance table for survey question #3.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SGNCLR	3	2.54	0.85	1.05	0.3779
AGE	1	1.54	1.54	1.92	0.1718
VISCON	1	1.10	1.10	1.36	0.2483
SGNCLR*AGE	3	4.83	1.61	2.00	0.1247
SGNCLR*VISCON	3	1.50	0.50	0.62	0.6053
VISCON*AGE	1	1.53	1.53	1.90	0.1733
SGNCLR*AGE*VISCON	3	1.52	0.51	0.63	0.6002
SNUM(SGNCLR, AGE, VISCON)	54	43.45	0.81		
Total	69	58.01			

*p<0.05

Table Z-7. Pairwise comparisons for survey question 4, assessment by sign color.

Sign Color Background	Difference between Rank Sums z(alpha=0.05, #c=6)=2.638, $z_{critical}$ = 38.83
Orange vs Purple	7
Orange vs Light Blue	22
Orange vs Coral	75*
Purple vs Light Blue	29
Purple vs Coral	82*
Light Blue vs Coral	53*

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

Table Z-8. Pairwise comparisons for survey question 5, assessment by sign color.

Sign Color Background	Difference between Rank Sums z(alpha=0.05, #c=6)=2.638, $z_{critical}$ = 38.53
Orange vs Purple	30
Orange vs Light Blue	32
Orange vs Coral	30
Purple vs Light Blue	2
Purple vs Coral	60*
Light Blue vs Coral	62*

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

Table Z-9. Pairwise comparisons for survey question 6, assessment by sign color.

Sign Color Background	Difference between Rank Sums z(alpha=0.05, #c=6)=2.638, $z_{critical}$ = 39.42
Orange vs Purple	17
Orange vs Light Blue	12
Orange vs Coral	67*
Purple vs Light Blue	29
Purple vs Coral	84*
Light Blue vs Coral	55*

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

VITA

Julie A. Barker

In 1991 Julie graduated with a B.S. in Aerospace Engineering from Virginia Polytechnic Institute and State University. She went on to work more than 3 years at Computer Sciences Corporation, where she provided launch and mission operations support for NASA satellites at the Goddard Space Flight Center in Greenbelt, Maryland. She returned to Virginia Tech in 1995 to pursue a M.S. degree in Industrial and Systems Engineering, with an emphasis in Human Factors Engineering and Safety, and currently holds a 4.0 grade point average. As a graduate student, Julie has worked as a teaching assistant in human factors engineering and as a research assistant in the field of transportation safety. She has also served as Treasurer of the Virginia Tech Student Chapter of the Human Factors and Ergonomics Society (1996) and as Treasurer of the Virginia Tech Student Chapter of the American Society of Safety Engineers (1997).