SHOULD THERE BE A UNIFORM NATIONAL COLOR FOR DOT VEHICLES?

Edward L. Kocan
North Carolina Department of Transportation

ABSTRACT

All state departments of transportation (DOTs) share a concern for employee safety, and for decades have chosen highly visible colors for their on-highway equipment to reduce accidents. This area is being reviewed by many DOTs due to the pressures of higher costs, tighter budgets, environmental regulations and quality problems involving color consistency. Color quality control and environmental concerns shared by most states are briefly reviewed. Considerations for implementing a definitive paint/marking standard are discussed. Reducing costs, meeting tighter environmental regulations, and implementing a standard color/marking may be practical objectives. The benefits of uniformity in color/markings among states such as reduced paint costs and increased safety for interstate travelers may be worthy of the combined efforts of state DOTs. A national research study is proposed on relative conspicuity of highly visible colors, markings, driver reaction times, and evaluation of functional considerations.

INTRODUCTION

The high visibility of on-highway equipment has long been considered an important concern for highway workers who are vulnerable to high speed traffic. This safety area is being reviewed by many DOTs due to the pressure of higher costs, tighter budgets, environmental regulations, and quality problems involving color consistency. Also, more recent studies of color conspicuity and evaluation of other markings, such as retroreflective and fluorescent materials, suggest more effective means to promote safety. The purpose of this paper is to propose a study of up-to-date safety marking techniques. A method which is highly effective, minimizes costs and accommodates growing environmental regulation is a worthwhile objective. The methods could include a range of options. Considering the psychological aspect of conspicuity and the economics of uniformity, a single uniform identification may be most desirable.

BACKGROUND

All state DOTs have shown concerns for safety by painting on-highway equipment in colors considered highly visible. An exhibit prepared by the Arkansas State Highway and Transportation Department for the Southeastern State Equipment Managers in 1992 demonstrated the colors used by 12 DOTs and a unanimous concern for safety and awareness of the positive effects of good visibility. Most colors were in the yellow or orange family although several states were using white. Typical colors were Omaha Orange, Federal Yellow No. 13538, and GM Orange No. WA-9408. These colors are difficult to distinguish from most state colors.

Hagler (*1*) presented Texas DOT experiences to the 9th Equipment Management Workshop (1992) and concluded that nonstandard paints cause longer delivery times and additional costs for equipment. Noted were the high light reflection of white and shorter delivery periods when manufacturers' standard colors were ordered. Texas DOT has changed to manufacturers' standard white for all on-highway equipment, Federal Yellow (13538) for all off-road equipment, and standard light colors for sedans.

The original Arkansas display generated considerable interest and in fact so many other DOTs have borrowed the display the North Carolina DOT reassembled the chips last year to prepare a display for its own use. In the period since the original display and following the presentation by the Texas DOT, several additional states have changed their colors to standard white. Several states outside the southeast such as Texas, Ohio, Connecticut, and Pennsylvania have met with the southeast group and their colors were included with the display.

A summary of state colors is provided in Table 1. States are placed in three groups: orange, yellow and white. Their official colors are listed along with a representative color. All of the oranges are extremely close to Omaha Orange. The group with the biggest differences is the yellow and among these, the N. C. Highway Yellow is probably the most different. With all the different paint colors specified by these 16 states, there are basically three colors: Omaha Orange, Federal

TABLE 1 ON-HIGHWAY EQUIPMENT COLORS (SOUTHEASTERN STATES EQUIPMENT MANAGERS MEETING)

STATE	OFFICIAL COLOR	COLOR MATCH
Connecticut	Omaha Orange	Omaha Orange
Louisiana	PPG-Delstar #60156	Omaha Orange
Mississippi	Omaha Orange	Omaha Orange
Tennessee	Omaha Orange	Omaha Orange
Virginia	GM Orange #WA-9408	Omaha Orange
Florida	Fed. Yellow #13538	Fed. Yellow #13538
Georgia	DuPont #174AH	Fed. Yellow #13538
No. Carolina	DuPont Centauri #54701AK	Fed. Yellow #13538
Pennsylvania	PPG # DU82546	Fed. Yellow #13538
So. Carolina	DuPont Centauri #LFG8112	Fed. Yellow #13538
Alabama	Standard White	Standard White
Arkansas	Standard White	Standard White
Kentucky	Standard White	Standard White
Ohio	Standard White	Standard White
Texas	Standard White	Standard White
West Virginia	Standard White	Standard White

Yellow and standard white. There is some move toward standardization as evidenced by states changing to standard white.

RECENT NORTH CAROLINA EXPERIENCE

North Carolina DOT changed its paint specification several years ago to exclude lead and chrome content. Subsequently, suppliers failing to match North Carolina DOT Highway Yellow became a problem. The new paint specification was more acceptable from an environmentalist view but it caused supply problems. First, obtaining paints to match the color was difficult for equipment suppliers since vendor cross reference information was not readily available. Second, the supplier who originally formulated the paint supplied it with volatile organic compound (VOC) levels that present problems using the paint in North Carolina DOT shops.

Problems associated with accepting various shades of color received with new equipment purchases were resolved by providing specification paint chips. Using these chips to specify color, identifying acceptable alternative paints and providing reference for equipment inspection made it easier to apply paint color discipline early in the delivery process. North Carolina DOT has looked at the use of color measuring instruments, in the color acceptance process but has settled on a simpler approach. Visual inspection is the most widely used matching procedure, so North Carolina DOT matches chips from suppliers with the standard chips of North Carolina DOT Highway Yellow. This provides an early opportunity to resolve differences in color before a production run is initiated.

The problems experienced upon change in paint specification by North Carolina DOT may be repeated as environmental regulations change. More restrictive regulations on VOC have prompted increased interest in water base paints, for example. A new potential problem for paint suppliers is the ability to match the high gloss of present paints with water-based paints.

There are likely additional equipment costs due to specifying nonstandard colors. There will be problems in changing paint formulations to adjust to new environmental regulations. From a national perspective these problems are compounded dramatically by the fact that many states have their own special colors.

FACTORS AFFECTING CONSPICUITY

Conspicuity is a term similar to the layman's concept of visibility but it also includes the act of recognition and psychological effect on the viewer. The psychological effect will be explained below. Olson (*2*) defined a conspicuous object as "one that will, for any background, be seen with certainty $p>90\%$ within a short observation time ($t=250$ MS) regardless of the location of the object in relation to the line of sight." Review of past studies shows important factors affecting conspicuity defined below.

Color

Color has been defined by researchers in precise mathematical terms. One of the more widely used systems for specifying colors in three dimensional space was developed in 1905 by the artist, Albert H. Munsell. This system was developed 23 years before instrumentation was available to measure color.

The Munsell system uses three attributes to specify a particular color numerically:

- L = Lightness - distinguishes "light" colors from "dark" colors,
- C = Chroma - is used to show how concentrated a color is or how different it is from gray, and
- H = Hue - is the attribute of color perception by which an object is judged to be red, yellow, green or blue.

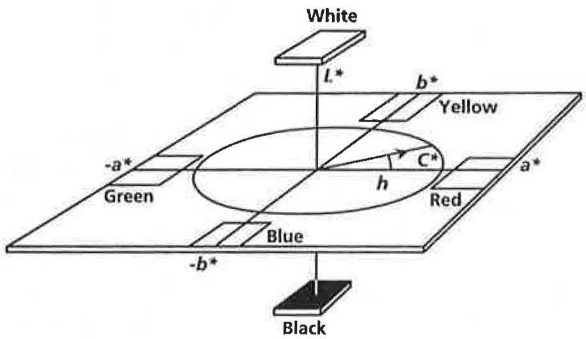

FIGURE 1 CIE 1976 (L*A*B*) color space.

The systems for specifying colors have been refined over the years and instrumentation is available to measure color. The Commission International De L'Eclairage (CIE) systems, presented in Figure 1, are commonly used (*3*). The CIE L*C*H* system uses mathematical expressions for the attributes defined above. The L*A*B* system that is also shown in Figure 1 uses different mathematical expressions to define color.

Light Sources

Color perception is partially a result of the light source. With today's street lighting and automotive light technologies, there are a variety of light sources. A color is seen because the surface reflects light of wavelengths producing that color perception. Different light sources produce light in different compositions of wavelengths. Figure 2 shows Spectral Power Distribution data for a few of these light sources (*4*). This effectively can make a color appear different. An illustration of the result is shown in Figure 3, which is taken from a study of colors and signs in workplaces (*5*). This data shows many instances where less than 50% of the observers recognized orange when viewed under Low Pressure Sodium Light. Typical light sources are Daylight, Incandescent Light, Cool White Fluorescent Light, Clear Mercury, Metal Halide, High Pressure Sodium and Low Pressure Sodium.

Contrast

How well one sees a color depends upon the background. For example, the visibility of white vehicles against a snowy or cloudy background is poor. Contrast is usually defined in terms of a black object on a white background but other logical combinations of colors should be considered.

Retroreflectivity

This term applies to reflection characterized by the flux in an incident beam being returned in directions close to the direction from which it came. There are several types including prismatic and spherical lenses. This aspect has been evaluated in studies by Olson (*2*), Aoki

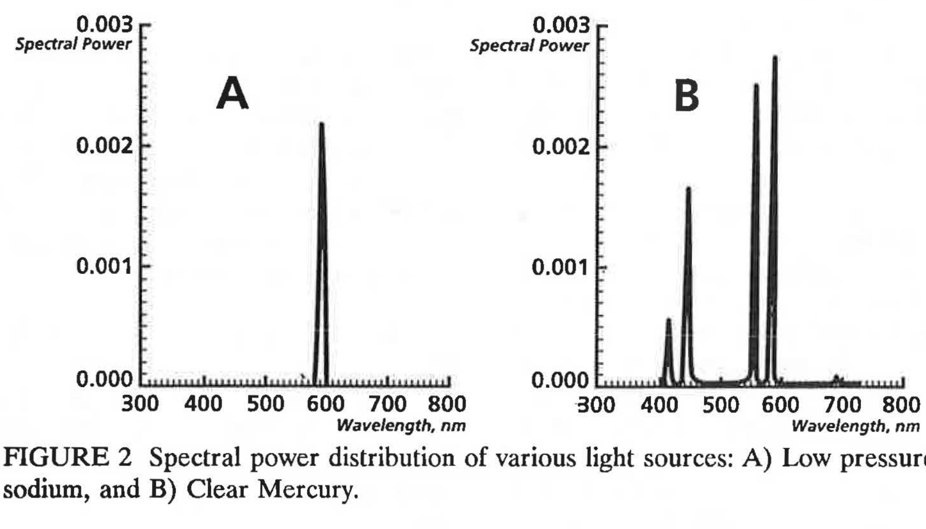

FIGURE 2 Spectral power distribution of various light sources: A) Low pressure sodium, and B) Clear Mercury.

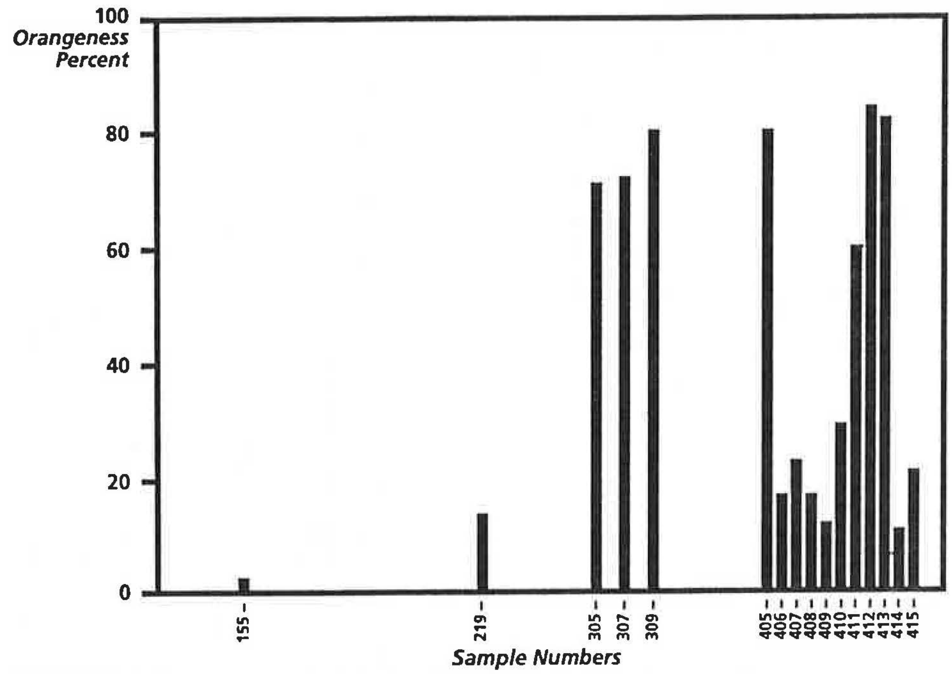

FIGURE 3 Percentage of trials in which designated color samples were identified as orange under high pressure sodium light.

(*6*), and Glass (*5*). Results from the work by Aoki (*6*) are shown in Figure 4, and show those retroreflective colors such as blue, red and green show up as much brighter than yellow.

Color Vision Defects

Collins (*3*) points out that color interpretation is complicated by the fact that 8-10% of the population has either inherited or acquired color vision defects. A frequent defect is the ability to perceive mid-wavelength pigments. Aging or acquired vision defects usually affect the short wavelength portion of the spectrum.

Pattern

Olsen (*2*) investigated use of retroreflective materials to upgrade marking systems on large trailers. Laboratory and field studies were conducted to assess the use of a pattern in the retroreflective material, the form of the pattern, the placement of the pattern, configuration, interference with other signals, the effect of environmental dirt on the performances of the marking systems and the durability of retroreflective material in this use. Figure 5 shows patterns recommended for marking large trailers.

Psychological Behavior

Reviewing articles in the literature, one becomes aware of four stages in responding to a situation: one detects, recognizes, decides to react, and then acts. For example, an English Study (*7*) noted that white is a passive color and communicates no sense of urgency. This report also concluded that a slight mixture of green with yellow was found to have psychological value and tends to be associated with unpleasant things. The behavioral assessment by Collins (*8*) raises questions about the role of color in determining sign visibility. Consistency, wide acceptance and identification of hazard situations requiring reaction are the desired psychological behavior.

FUNCTIONAL CONSIDERATIONS

Considering the problems described earlier, some practical aspects have to be considered when using paint

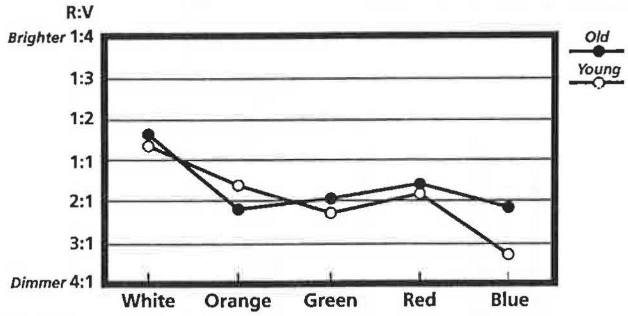

FIGURE 4 Luminance ratio of other colors to yellow, when subjects judged them equal in brightness. *(6)* "Old" subjects were 60-75, "Young" subjects were 18-30.

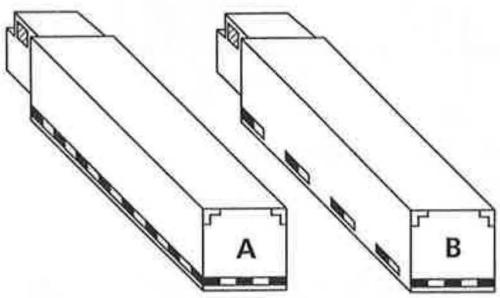

FIGURE 5 A) Recommended configuration of retroreflective materials, and B) optional treatment with gaps on sides. *(2)*

or other marking systems. Some considerations are noted below and should be part of the evaluation process for selecting effective marking systems.

Durability

How long does the material retain the desirable conspicuity attributes, and what are the frequency and cost of replacement?

Environmental Compliance

Is the material environmentally safe and will it meet existing Federal and State Environmental Regulations? Are there potential threats to future use because of developing environmental issues?

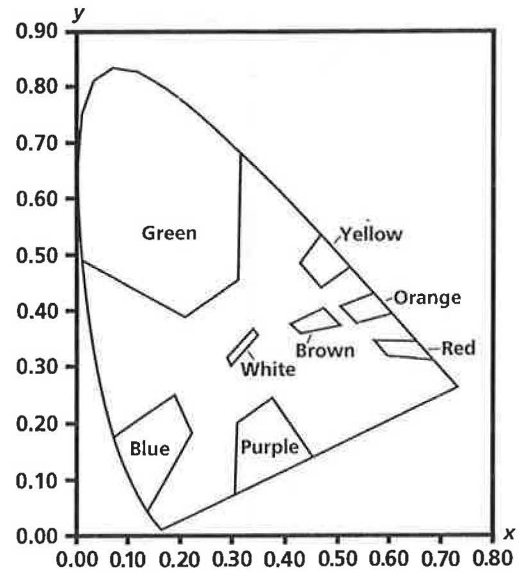

FIGURE 6 Chromaticity regions specified by the CIE for ordinary colors under D65, daylight *(3)*. The CIE Tristimulus Values are x and y. Following the perimeter changes hue and saturation changes from center to outer edges.

Adaptability to Change

How easily will adjustments to markings be implemented in cases of future regulatory changes and what are the costs involved?

Matching

How readily can materials be matched after repairs of a vehicle or when the material must be replaced due to loss of function? What are costs of replacing and matching materials and are large inventories of materials needed?

Uniformity

Is it effective to describe a range of colors or markings which meet the requirements for conspicuity and functionality, such as the colors shown in Figure 6 (*3*), or do other functional concerns indicate that a uniform marking is most desirable at either the state or national level? Are costs, psychological aspects of conspicuity and ability to change to regulatory requirements sufficiently enhanced by large scale uniformity?

PROPOSED RESEARCH PROJECT

The studies conducted so far provided a great deal of insight into conspicuity of various paint colors and markings. However, none of the studies have specifically addressed the complete spectrum of conspicuity factors for on-highway equipment. A research project to address on-highway equipment is outlined in Table 2.

A review of the referenced studies should provide an excellent start for accumulation of data needed for the proposed study and this would initiate Phase I. The data can be reviewed to determine the important factors and colors/markings to be included. The final product of this phase would be recommendations of colors/markings to be evaluated and laboratory tests recommended to obtain additional data on conspicuity factors.

Laboratory tests can be conducted in Phase II to supplement data needed to evaluate paint and marking alternatives. Functional considerations such as durability, environmental compliance, adaptability to change, ease in matching and benefits of uniformity would also be evaluated in Phase II. There is no intent to place economic values on human lives, but cost-benefit analyses of the functional considerations are necessary to utilize funds in a manner where they will be the most effective in promoting safety.

As part of this evaluation, assessment can be made whether paints and/or markings should be defined as a range of acceptable colors and configurations or whether sufficient benefits exist for establishing requirements for uniformity at either the state or national level. The final product of Phase II would be the recommended colors/markings for field test and the recommended test program.

The Federal Highway Administration (*9*) is conducting an evaluation program for fluorescent strong yellow green crossing signs. The field tests of this program provide some insight into the field testing that would be necessary in Phase III of the proposed project. It is important that the best alternatives be field tested in the best representation of the environment where they will be used. The psychological aspects of conspicuity can best be evaluated in the field tests. Considerations for field test include the number of alternatives to be evaluated. The number of alternatives should be reduced to a minimum through literature assessment and laboratory testing. Additionally, the various situations for field tests must be selected such as daylight, twilight, or evening and conditions such as clear, cloudy and snowy days.

The number of observation points, observers and observations to be recorded must be chosen best to evaluate the alternatives.

TABLE 2 PROPOSED RESEARCH PROGRAM

PHASE I

A. Literature review
B. Determine colors/marking for evaluation
C. Determine conspicuity factors to be considered
D. Recommend colors/marking and laboratory tests for relevant conspicuity factors

PHASE II

A. Conduct laboratory tests
B. Obtain data and evaluate functional considerations
C. Determine relative effectiveness of paint/markings for conspicuity
D. Determine rank of alternatives including functional considerations
E. Recommend alternatives for field tests
F. Recommend field test plans

PHASE III

A. Field test most promising alternative(s)
B. Obtain base case for comparison
C. Recommend most effective alternative including most desirable amount of uniformity

CONCLUSION

The research study proposed above will utilize existing studies and will supplement research data in areas where needed. The project also includes field testing in the actual environments where the markings are used and will obtain factual, objective information. The recommendations will provide credible, objective information which is not currently available. This information will provide an improved basis for DOTs to decide the best means to provide safe identification markings for on-highway equipment.

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