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Standard Practice

BASELINE REQUIREMENTS FOR COLOR USE

IN AIR TRAFFIC CONTROL DISPLAYS

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1. SCOPE

This standard establishes Federal Aviation Administration (FAA) requirements to prevent generic problems associated with color use in general Air Traffic Control (ATC) displays. This standard also establishes a systematic method to assess the benefits and the potential disadvantages of color use in ATC displays from an ATC operational perspective to ensure that the use of color enhances task performance and does not introduce undesirable safety risks.

Through site investigations, we found that color is used primarily for three purposes associated with ATC task performance.

1. Draw attention to urgent information.
2. Identify data categories.
3. Segment complex scenes.

In addition, we identified many color and visual factors pertinent to the controllers' task performance, and then we classified them into two major categories: (1) *Factors that make the use of color beneficial for a given purpose* and (2) *Factors that have the potential to negatively affect task performance*.

Based on the results and findings from cognitive and visual research, we developed two sets of requirements to design color schemes in ATC displays. The first set ensures the effectiveness of color to achieve the intended purpose, and the second set mitigates the potential disadvantages of color use.

Many researchers have published color use guidelines that provide information about how color works and how to choose color schemes in displays (Ahlstrom & Longo, 2003; Cardosi & Hannon, 1999; Narborough-Hall, 1985; NASA Color Usage Web Page, 2004; Reynolds, 1994; Van Laar, 2001).

We based this document on information derived from ATC operations. Its purpose is to serve as the baseline requirements for color use from an ATC operational perspective. Its audience includes developers of ATC technologies, human factors practitioners, and designers who will select color in ATC displays.

2. APPLICABLE DOCUMENTS

2.1 Government Documents

The following government document forms part of this standard. If there is a conflict between the document and the standard, the standard **shall** supersede the document.

Ahlstrom, V., & Longo, K. (Eds.). (2003). *The human factors design standard: Human interface guidelines* (HF-STD-001). Washington, DC: FAA. Retrieved January 19, 2007, from http://hf.tc.faa.gov/hfds

2.2 Non-Government Documents

The non-government documents form part of this standard. If there is a conflict between the referenced documents and the contents of this standard, this standard **shall** supersede the referenced documents (see References section).

3. REQUIREMENTS

Throughout this document, we will use "**shall**" and "**should**" statements that are common in design specifications. A **shall** statement refers to a described, testable condition that must be met. A **should** statement refers to a condition that is not completely testable but is recommended. A paragraph of explanation accompanies most **shall** and **should** statements in this document that provides additional information about the statement and the related scientific literature.

We present the main body of the FAA's requirement for color use in ATC displays in the following three sections:

- **Section 3.1** requires that the use of color in an ATC display **shall** be associated with one or more purposes that assist with ATC task performance. The section also describes the primary purposes of *attention*, *identification*, and *segmentation*.

- **Section 3.2** requires that the use of color **shall** be effective for its given purposes and describes the conditions under which the use of color is effective.

- **Section 3.3** requires that the use of color **shall** avoid potential disadvantages to task performance. The section describes the conditions under which the use of color can limit performance and then pose safety risks. To meet the color use requirements for ATC displays, all colors used in a display **shall** comply with the standards specified in each of the three sections.

Many requirement items in this document specify color and color differences in International Committee of Illumination (CIE) chromaticity coordinates (CIE, 1931). However, colors are expressed in *Red*, *Green*, and *Blue* (RGB) coordinates in software. The same RGB values may look different on different types and models of computer monitors. Therefore, developers have to derive the RGB values from the CIE coordinates for every system they build. Detailed information regarding color coordinate transformations and color calibration can be found in Berns (1996).

3.1 How to use Color in ATC Displays

3.1.1 *When to use Color*

Color **shall** be used only when it is associated with a purpose that aids task performance. The use of color in ATC displays is typically associated with one of the following three purposes: *attention*, *identification*, or *segmentation*.

3.1.1.1 Attention

A salient color is used to direct users' attention immediately to alert or to direct to emergent information. In this application, a color generally means "urgent, critical, immediate attention is needed." The effective use of color means that the colored target can automatically capture a user's attention or "pop-out" in a complex display (*Pop-out* means that a visual target can be effortlessly detected irrespective of the amount of local visual materials).

3.1.1.2 Identification

A set of colors is used to identify data categories when data are presented dynamically, intermingled, or distributed in an irregular way on a display. In this application, each color is associated with a specific meaning. The effective use of color for identification means that searching by color for an item of a given category among many other items can be done effortlessly, reliably, and accurately.

Effortless often implies quick as well as ease in finding an item. *Reliable* means that selection is consistent and dependable. *Accurate* means that, statistically, the correct item is always selected and the incorrect item is never selected.

3.1.1.3 Segmentation

Different colors are used to organize information by segmenting a complex scene into distinctive visual objects. In this application, a color is not necessarily associated with a meaning. It is used to either integrate or differentiate data. The effective use of color for segmentation means that data displayed in the same color appear as a visual object separated from other data, so that a user will know where to look for related information. Such visual objects can be either spatially continuous regions (i.e., an image) or spatially discontinuous patterns (i.e., a figure).

Segmentation tasks include *regional segmentation* and *pattern segmentation*. Regional segmentation involves segmenting a spatially continuous region from its surrounding materials. Pattern segmentation involves integrating some spatially discontinuous items into one object and segmenting them from other displayed items.

3.1.2 *Color for Labeling*

Other than the three primary task-related purposes (*attention*, *identification*, and *segmentation*), color is occasionally used to label data. This application is typically used in the situation where many categories of data are displayed irregularly and intermingled across a display, yet there is insufficient space to label the data with text. Therefore, colors are used to label the data and a look-up table is provided to indicate the meaning of each color.

The use of color for this purpose appears similar to that for identification. However, the colors in this application are only for labeling, not for controllers to efficiently and reliably search the data included in a given category. Thus, as long as the colors are visually distinguishable and a look-up table is provided, they can adequately serve the purpose. Because the application of color for data labeling is rare and easy to use, this kind of color use is not included in Section 3.2.

3.2 Ensuring the Effectiveness of Color use

We organized these requirements with respect to the three primary task purposes of color use in ATC displays. For each purpose, we use **shall** and **should** statements to describe the conditions required for the color use to be effective. To utilize these requirements, first determine the task purpose of a color and then determine the conditions for that purpose. Only when all the conditions for a given purpose are met can the use of color be effective. If a color is used for more than one purpose, then all the conditions under those purposes need to be met for the color to be effective.

3.2.1 *Attention*

3.2.1.1 Luminance

The apparent luminance of the target that requires attention **shall** be higher than the luminance of its distractors.

Distractors of a target are defined as other visual stimuli displayed in the view field surrounding the target. The pop-out effect depends on the salience of a visual target relative to the distractors. Brightness (i.e., luminance) contributes to salience more than color; thus, a brighter target among dimmer distractors can easily pop out, whereas a dimmer target among brighter distractors fails to pop-out regardless of its chromaticity (Li, 1999; Treisman & Souther, 1985). In addition, high luminance is desirable for mission-critical targets in an ATC work environment because the targets need to be visible and salient even when controllers reduce the brightness of their computer screens.

The apparent luminance is the luminance of a visual object perceived by the eyes. It can be estimated as the area of the object multiplying the physical luminance. For instance, the apparent luminance of a text box filled with a color is about five times higher than the apparent luminance of the text of the same color because text only takes about 20% of the area.

3.2.1.2 Chromaticity Difference

The chromaticity difference[1] between the target and distractors **shall** be greater than 0.24 in CIE uniform chromaticity coordinates if the apparent luminance of the target is 20 cd/m^2 less than that of distractors.

3.2.1.3 Number of Distractor Colors

The number of distractor colors **shall** be fewer than five. For the best effect, the number of distractor colors **should** be minimized to no more than two or three (Treisman & Gelade, 1980).

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[1] A color is specified by two variables, *x* and *y* in CIE chromaticity coordinates, and is also specified by two variables, u' and v' in CIE uniform chromaticity coordinates. The values of u' and v' can be computed from *x* and *y* through two non-linear equations: $u' = 4x / (-2x+12y+3)$, and $v' = 9y / (-2x+12y+3)$ (CIE, 1931, 1986). The chromaticity difference between two colors is calculated as $((\Delta u')^2 + (\Delta v')^2)^{½}$.

3.2.2 *Identification*

3.2.2.1 Color Naming

The colors used to identify data categories **shall** be reliably and consistently named. Basic colors **should** be chosen for the purpose of identification. Color research has found that 11 basic colors (red, green, yellow, blue, pink, brown, purple, and orange; as well as three achromatic terms: black, white, and gray) can be named reliably and consistently across populations of different geographic regions and cultures (Boynton & Olson, 1990). In addition, magenta and cyan are among the consistently namable colors. These colors are maximally separated in the color space.

3.2.2.2 Chromaticity Difference

If non-basic colors are used for *identification*, the chromaticity differences between the colors **shall** be greater than 0.04 in CIE uniform coordinates. The chromaticity difference between the colors **should** be significant enough for each color to be distinctively named. The minimal chromaticity difference for colors to be distinctively named is about 10 times the color discrimination threshold (Boynton, MacLaury, & Uchikawa, 1989; Poirson & Wandell, 1990).

3.2.2.3 Number of Colors

The number of colors used to identify data categories **shall** be fewer than seven.

3.2.2.4 Luminance Difference

The luminance difference between the colors **shall** be less than 20 cd/m^2 , unless a specific color is used for both *attention* and *identification*. The luminance difference between the colors **should** be minimized so that none of the colors is much brighter than the others. When the luminance difference between two colors is greater than 20 cd/m^2, the data displayed in a brighter color can pop-out to capture the user's attention (Nagy & Sanchez, 1992). Thus, a bright color becomes a distraction when users search for the data displayed in the dimmer color. Consequently, users tend to miss the data included in that category, and the dimmer color becomes ineffective for identification.

3.2.3 *Segmentation*

3.2.3.1 Luminance Ratio and Chromaticity Difference

For regional object segmentation, the chromaticity difference between the object and its surrounds **shall** be greater than 0.004. Alternatively, the luminance ratio, defined as the absolute luminance difference between the object and surrounds divided by the luminance of the object, **shall** be greater than 5%. The effect of luminance in segmentation is determined by the ratio of the luminance difference to the baseline luminance of the object to be segmented.

For pattern segmentation, the color difference between the pattern and its surrounds **shall** be greater than 0.012. Alternatively, the luminance ratio **shall** be greater than 15~20% (McIlhagga, Hine, Cole, & Snyder, 1990).

3.2.3.2 Luminance Difference

The luminance difference between the colors **shall** be less than 20 cd/m^2. The luminance difference between data of equal importance **should** be minimized so they appear to have the same visual salience. Because the salience of a visual object increases with its luminance, having the luminance levels of the displayed data consistent with the levels of data importance can help to organize data priorities. On the other hand, less important data (i.e., background information) may be segmented by a lower luminance color.

3.2.3.3 Number of Colors

The object to be segmented **shall** consist of no more than two colors unless the object is composed of high-density textures of various colors.

3.3 Avoiding Potential Disadvantages of Color use

To avoid safety risks, the use of a color in an ATC display **shall** be checked for the presence of each of the following eight factors and meet the requirements of all statements provided.

3.3.1 *Low Text Readability*

The luminance contrast between the text and background **shall** be greater than the threshold Michelson contrast (30%) for error-free reading. Low text readability increases reading difficulty and may cause reading errors.

Readability is the property that permits an observer to read text easily on a screen irrespective of meaning (Legge, Rubin, & Luebker, 1987). It is primarily determined by the luminance contrast between the text and its background colors. Luminance contrast can be calculated as the difference between the text and background luminance divided by the sum of the luminance. Therefore, zero contrast means that the text and background have the same luminance, and 100% contrast describes the maximum luminance contrast such as the contrast produced by the combination of white and black. The text readability is trimmed to zero when both the text and background luminance is very low (typically less than 12 cd/m^2 for most computer monitors), regardless of the luminance contrast (Krebs, Xing, & Ahumada, 2002).

3.3.2 *Lack of Effective Redundant Cues*

The use of color for attention or identification **shall** be accompanied with effective redundant cues.

A lack of effective redundant cues means that color is the only cue to draw attention or identify data categories. Lack of effective redundant cues may result in loss of color-coded information when colors are viewed by color-vision-deficient users, from off-axis angles for flat panel displays, or under strong ambient light.

Table 1 lists the effectiveness of some frequently used redundant cues for different task purposes. For *attention*, typical effective cues include flashing/blinking and luminance (brightness); effective cues for *identification* include spatial location, distinctive shape, and text (Xing & Schroeder, 2006).

Table 1. Effectiveness of Redundant Cues Relative to Color for Various Tasks

Task	Flashing	Location	Luminance	Shape	Size	Text
Attention	E[a]	L[b]	E	NE[c]	NE	NE
Identification	NA[d]	E	NE	L	NE	L
Segmentation	NA	L	L	L	L	NE

[a]E = redundant cue is more effective than or at least as effective as color
[b]L = cue is less effective compared to color
[c]NE = cue is not effective for the task
[d]NA = cue is not applicable

3.3.3 *Color Complexity*

The number of colors used to identify data categories in a single display mode **shall** be fewer than seven.

Using colors for identification places additional demands on working memory. Moreover, exceeding the working memory capacity (about seven items) can cause users to make more omission errors when performing multiple tasks (Carter 1982; Cummings, Tsonis, & Xing, in press).

3.3.4 *Excessive Coding Sets*

A display **shall** use no more than three sets of colors to identify data categories. Multiple sets of color coding can increase cognitive workload and cause misinterpretation of information (Yuditsky, Sollenberger, Della Rocco, Friedman-Berg, & Manning, 2002).

3.3.5 *Experience Interference*

The use of a color **shall** be consistent with its reserved meanings, according to the color use conventions in ATC displays. Interference occurs when the meaning of a color conflicts with the controllers' previous experiences and may result in misinterpreting information and increasing the cognitive workload required to comprehend color meanings (Stroop, 1935). The following is a list of conventions for color usage in ATC displays:

- Red is reserved to draw attention to emergency or alert messages.
- Yellow is reserved to identify a target or data category that needs caution.
- Orange, purple or magenta, and cyan or turquoise are reserved to identify data categories.
- Green, white, and black are reserved to identify the normal status category.
- Non-basic colors, especially those in the green-blue domain (e.g., green-blue, gray-blue, and yellowish-green), are the typical choices for segmentation.

3.3.6 *Uncorrelated Coding*

When used for *attention* or *identification*, a color **shall** be fully correlated with a specific meaning in task performance; one color **shall** be used for a unique purpose, and information of the same category **shall** be represented by the same color.

Uncorrelated color coding causes coding uncertainty, which may decrease the accuracy of identifying data in a category and cause misinterpretation of color-coded information (Christ, 1975).

3.3.7 *Loss of Integration*

Dynamic data that need to be instantly related or compared for successful task performance **should** be displayed in the same or similar colors.

Displaying two sets of data in different colors reduces instant information integration between the data sets, because an operator is less likely to recognize the relationships between pieces of information when they are depicted in different colors.

3.3.8 *Distraction*

Simultaneous onset of multiple salient colors that need attention **should** be minimized. Salience of the alert information (taking into account size, shape, color, brightness, and motion) **should** relate to the operational criticality of the event.

The onset of a salient target causes distraction, which may decrease the detection of other significant events and result in loss of information even if the events are visually salient and are in the focus of view (DiVita, Obermayer, Nugent, & Linville, 2004).

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