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Color and Visual Factors in ATC Displays

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16. Abstract

Computer displays are one of the major sources of information for air traffic controllers to control traffic. Because the existing display technologies make it so easy to render color on computer monitors, color is being extensively used in air traffic control (ATC) displays. At present, the Federal Aviation Administration has no requirement for how color should be used in ATC displays. While the advantages of color may be apparent, many display designs suggest that ATC technology developers have not used basic human factors and color principles to optimize the advantages of color use in complex scenes such as those in the ATC environment. In addition, technology developers create their own unique color schemes. The lack of consistency in color use can be confusing. Moreover, little attention has been devoted to the potential negative effects of color use on controllers' task performance. In this study, we investigated color use in ATC facilities to understand the ways color is being used, the associated benefits, and its influence on task performance. We found that, while color use has some advantages for information processing, such as reducing workload and saving time, it also has disadvantages and may introduce negative effects on task performance. We identified the benefits of color use and provided rationales for how to use color properly to optimize those benefits. We also analyzed the negative effects of color use with respect to associated cognitive factors. Finally, we derived two checklists that evaluate advantages and negative effects of color use in ATC displays. These checklists can be used for design prototypes and acquisition evaluation.

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COLOR AND VISUAL FACTORS IN ATC DISPLAYS

INTRODUCTION

During the past decade, the introduction of new technologies and automation tools in the air traffic control (ATC) environment has involved the increasing use of color displays. Many ATC facilities introduced new computer-based automation tools and replaced old monochromatic computer monitors with new ones. The new monitors have the capability of displaying a wide range of color. As the result, color is used in many new ATC technologies and is being added to existing displays. Moreover, some ATC displays allow users to customize the colors. Consequently, the same automation tool may use different color-coding schemes across facilities or even within the same facility. For example, the Enhanced Traffic Management System (ETMS) was designed to accommodate users' color preference, and the Information Display System (IDS) allows personnel at each facility to determine their own color schemes.

The presence of color in visual displays can be used to attract attention, compare objects, or even convey emotion messages (Cole, 2004). Accumulated visual studies have shown that color is superior to achromatic visual attributes in many tasks such as searching for targets and organizing complex visual scenes (Christ, 1975). A fundamental mechanism for the superiority of color is that the human visual system processes color and achromatic forms separately through different anatomic pathways (Kaiser & Boynton, 1996). Only at the higher levels of brain information processing are signals about color and forms integrated. Therefore, while achromatic visual cues (such as luminance, shape, and text) are used to convey detailed information, color can be used as a distinctive dimension to organize achromatic information. Moreover, because color usually conveys less information than achromatic attributes, color-coded information can be apprehended faster and more easily. For example, many ATC displays use red texts for warning and alert messages. Thus, a controller can perceive an alert with a quick glance at the color instead of spending additional time reading the text.

While the advantages of using color in ATC displays seem apparent, its drawbacks are less apparent. For example, the sudden onset of a colored shape is useful to capture a user's attention (Yantis & Jonides, 1996). However, observers may miss other changes that occur simultaneously in the visual field, a phenomenon called "inattentional blindness" (Simons, 2000). Consequently, a controller may not notice the symbol of an aircraft entering into the displayed airspace if, at the same time, a color is onset (to signal another event) in the same display. Although situations like this might be infrequent, and the resulting performance errors may not occur on a daily basis, safety is a priority for ATC; thus, any use of color in ATC displays must consider both the benefits as well as the potential risks.

At present, the Federal Aviation Administration (FAA) has not established any formal requirement for color use in displays or systematic methods to evaluate the benefits vs. drawbacks of color use. Many existing guidelines for color use provide computer engineers and interface designers with some principles (Cardosi & Hannon, 1999; HF-STD-001, 2003). However, most guidelines have some shortcomings. The typical shortcomings include:

1) The guidelines often use visual and human factors terms that are unfamiliar to engineers and designers;
2) the guidelines usually emphasize how to optimize the advantages of colors but provide little information about their drawbacks; and
3) the guidelines are largely concerned with the perception of color instead of the effects of color on task performance.

These shortcomings have limited the application of the guidelines in display design and evaluation.

To understand the current status of color use in ATC displays, we conducted site visits to nine ATC facilities: three Air Traffic Control Towers, three Terminal Radar Approach Control facilities, and three En Route Traffic Control Centers. At each of these ATC facilities, we performed the following activities: 1) Learned how controllers used computer displays in the facility through briefings given by facility managers, supervisors, and technical staff; 2) observed how controllers used color information to perform tasks; 3) identified color usages and their relevance to ATC tasks; and 4) determined the purposes of color use and potential problems associated with color. In addition, we discussed with the facility representatives issues associated with the advantages and drawbacks of using colors in displays. The discussions significantly contributed to our task of identifying color and visual factors that might negatively affect ATC task performance.

To ensure that the use of color in ATC displays enhances task performance and does not introduce any undesirable safety risk, it is necessary to have a systematic method to assess the benefits and potential negative effects of color use. Through the facility visits, we identified color and visual factors that were pertinent to controllers' task performance. In this report, we classified those factors into two major categories:

1) factors that make the use of color effective for given task purposes; and
2) factors that might negatively affect task performance. For each factor, we present examples identified in ATC displays and the rationale in the scope of cognitive and visual research.

Finally, we developed two checklists that would allow a quick evaluation of color use in ATC displays. We studied the literature to provide rationales for the development of the color-use checklists. Thus, the checklists are based on basic research findings and adapted for engineering applications.

We need to point out several limitations of this report. First, due to the limited time at each facility, we were unable to systematically collect data about the color use from all the ATC displays. Therefore, this report is limited to qualitative descriptions of the facts learned through our facility visits. Second, while we cited many experimental studies in the literature to provide rationales for the checklists, we did not intend to perform a comprehensive literature review of color information processing. Third, we did all the analysis of color use for personnel with normal color vision; the issue of color vision deficiencies was beyond the scope of this report.

RESULTS

Color and visual factors that contribute to the effectiveness of color use

Task purpose of color use in ATC displays

Previously, Xing and Schroeder (2005) reported that color in ATC displays was primarily used for one of three task purposes: 1) To draw attention. Colors are often used to encode information that needs to be attended to instantly, such as an alert or emergency. 2) To identify certain types of information so that searching for the information in complex scenes can be done more efficiently. In this application, each color is associated with a distinctive meaning. For example, a controller may use yellow to outline a restricted airspace on the display; the distance of an aircraft to that airspace can be subsequently displayed in yellow text. 3) To organize information by segmenting a complex scene into visual objects so that controllers can easily appreciate what and where objects are. For example, the functional menus of a display may appear as dark green; thus, they are visually segmented from other materials on the display. In this kind of application, color is not associated with any specific meaning. Accordingly, Xing and Schroeder classified task purposes of color use in ATC displays into three categories: *attention, identification,* and *segmentation.* In this section, we present the benefits of color use and the factors that enable color to achieve the benefits for each category.

Attention

Controllers need to instantly detect critical information in ATC displays without serially searching complex scenes, so the target that represents critical information should immediately become obvious to capture attention. This phenomenon is called "pop-out" in vision research (Treisman & Gelade, 1980). Pop-out is especially useful when targets need to be detected in large displays, because targets located in the peripheral visual field can be quickly brought to the fovea for detailed inspection. For example, a typical radar display such as the Display System Replacement (used by controllers in En Route Traffic Control Centers) includes a central area for current flight situations and one or several menu bars along the sides of the display. Controllers spend a great deal of time scanning the flight situation area. However, an alert message that appears in the left-top corner of the display may require immediate detection. Because a controller does not often look at the corners, that message may go unnoticed, unless the message pops out and captures the controller's attention.

The pop-out effect depends on the difference between the target and other displayed materials (called *distractors*) within the surrounding visual field that typically spans a view angle of 20~40 degrees. Because achromatic attributes are used in the form of text, shape, graphics, and shades to represent detailed information, color appears as a distinctive dimension to create conspicuous differences between a target and distractors. Thus, pop-out of color-coded information in complex scenes is extremely efficient and desirable (Treisman & Gelade, 1980). Several studies compared the effectiveness of various visual cues in pop-out and concluded that color was next to flicker and brightness but superior to shape and size in drawing attention (Christ, 1975). While flicker is the most effective visual cue to capture attention, its use should be limited because it produces tunnel vision, during which the observer focuses on one target and ignores other objects in the visual field. A great deal of visual research has been devoted to studying the conditions under which pop-out could be reliably induced. We summarized the important results as follows:

1) Color can effectively draw attention when a colored target is brighter than distractors, and the size of the target is equivalent to, or larger than, most

distractors (Nagy & Sanchez, 1992; Treisman & Souther, 1985).

2) A color can be specified by two factors: luminance and chromaticity. Either luminance difference between the target and distractors or chromaticity difference can induce pop-out. The threshold luminance difference is about 20cd /cm^2 for small stimuli (0.5~1.5 degree view angle) in large displays (Nagy & Sanchez, 1992). The threshold color difference is about 60 times that of the color discrimination threshold, at which two filled areas placed side-by-side can be discriminated. The discrimination threshold varies with the wavelength of colors and illuminant conditions (Wyszecki & Fielder, 1971). Nevertheless, industrial applications typically take the threshold as 0.004 in CIE color difference coordinates (see Appendix A for CIE chromaticity). By this standard, we estimated that the threshold color difference for attention is 60 *0.004=0.24.
3) Color is effective in inducing pop-out when other materials of comparable or larger sizes in the view field are composed of no more than two or three colors. With increasing variation of distractors, target salience decreases and the pop-out effect diminishes (Treisman & Gelade, 1980).

Identification

While our sensory system can perceive a large volume of information in an analog manner, our cognitive system can only process a few pieces of information at a time. Therefore, an effective way to reduce cognitive workload is to organize information in complex visual scenes into categories and denote the categories with visual attributes that can be easily identified. Such tasks are called *identification*. One example is the representation of precipitation in ATC displays. Although precipitation varies continuously, it is categorized into six levels in the ATC environment: Levels 1-2 for light weather, Levels 3-4 for moderate heavy weather, and Levels 5-6 for severe weather. Controllers make decisions by identifying the weather levels instead of the precise value of the precipitation.

Color is often used denotatively to identify an object. The task of using color for identification is essentially the task of color naming in which observers can associate targets with specific color names. In the example of weather precipitation, the six levels are displayed with different colors. Seeing some areas filled with red, a controller can immediately recognize the presence of severe weather.

In the ATC environment, identification of two stimuli is usually performed at separate spatial locations and times. Typically, a controller remembers the color by its name and searches for the target identified by the color. Thus, such color-based identification tasks involve the use of memory. Several studies demonstrated that color is much more effective than in identification tasks where memory is required. Moreover, color becomes increasingly more effective as recall of memorized items is delayed (Sachtler & Zaidi, 1992; Young & Nagy, 2003). For example, when used to identify information such as aircraft shapes, geometric shapes, and alphanumeric signs, color was significantly better in terms of accuracy than size, brightness, shape, and text (Christ, 1975). Also, the superiority of color to achromatic cues is more evident as the visual scenes became more complex or the difficulty of identification tasks increased.

Next, we summarized the results in the literature about how to effectively use color for identification.

1) Basic colors are more effective than others for identification tasks because they are maximally segregated in the color space and can be named reliably and consistently across subjects. The basic colors include red, green, yellow, blue, purple, brown, orange, pink, and three achromatic colors, black, white, and gray. (Boynton & Olson, 1990; Smallman & Boynton, 1990).
2) For non-basic colors, the minimal color difference is about 9-10 times the color discrimination threshold to effectively identify information (Boynton, MacLaury, & Uchikawa, 1989).
3) The maximum number of colors that can effectively identify information is 6 or 7. Beyond that limit, color has no advantage over achromatic cues (Carter, 1982).

Segmentation

The human visual system organizes complex scenes into meaningful objects. To appreciate what and where particular objects are present, the visual input is organized by a filtering procedure that has been termed *segmentation* (Pinker, 1984). Segmentation is crucial when using an automation system with a cluttered display and varying task demands. For example, a controller can spatially segment the aircraft situations area from the menu areas in a radar display. Thus, when controllers need to find a command in the menu bars, they can direct their attention to the menu area instead of searching the entire display. Since ATC displays are usually very complex, segmentation is necessary to reduce controller workload.

Segmentation is based on uniformity and consistency of elements. An area composed of uniform elements can be easily segmented from its surroundings. Since the human visual system processes color separately from achromatic visual features, color is one of the ways to segment a display into separate regions. In complex scenes like those of ATC displays, color is more effective and is processed faster than achromatic cues for segmentation because achromatic cues are usually used with explicit meaning (Nothdurft, 1993).

Segmentation tasks include regional segmentation and pattern segmentation. Regional segmentation involves segmenting a spatially continuous region from its surrounding materials. For instance, a terminal radar display called Standard Terminal Replacement System (STARS) uses a circle or polygon filled with beige to segment a restricted airspace from non-restricted airspace. Specifically, Yamagishi and Melara (2001) demonstrated that chromaticity information is more effective than luminance in regional segmentation. On the other hand, pattern segmentation involves integrating some spatially discontinuous patterns into one class and segmenting them from other patterns. For example, another terminal radar display, called Automated Radar Terminal System (ARTS) Color Display (ACD), represents datablocks of aircraft owned by a controller in white and those of unowned aircraft in green. By doing so, the owned aircraft and unowned datablocks are visually segregated. These two types of segmentation tasks have different requirements for color use.

Below are some tips from extensive visual studies of segmentation:

1) A region consisting of two or more colors is likely to be confused with other regions made up of many colors (Julesz, 1965); thus, it may not be reliably segmented from others.
2) Both chromaticity and luminance differences between regions or patterns can result in segmentation; however, chromaticity is more effective than luminance. For regional segmentation, the threshold color difference is equivalent to the discrimination threshold, at which two filled areas placed side-by-side can be reliably discriminated. For pattern segmentation, the threshold color difference is about 3~5 times the discrimination threshold. The luminance factor in segmentation is determined by the ratio of the luminance difference to the baseline luminance of the object to be segmented. The threshold ratio is about 5% segmentation of uniform areas placed side-by-side and 15~20% for patterns. (McIlhagga, Hine, Cole, & Snyder, 1990).

A checklist of color-use effectiveness

Based on the observed task purposes of color use in ATC displays and the rationale described in the preceding section, we developed a checklist of the color and visual factors that are essential to ensure the effectiveness of color, as shown in Table 1. The checklist is organized with respect to task purposes. The elements in the table, from left to right, are task purposes, factors contributing to the effectiveness of color use, conditions with which color use is effective for the purpose, and checkboxes that would be filled with “Yes” if a condition is met or “No” otherwise. To use this checklist, one first needs to determine the task purpose of a color. For each purpose, several factors contribute to the effectiveness of color use. When all the conditions for a given purpose are met, the use of color is effective for the purpose.

An example of the application of the checklist

We use the color scheme of ACD datablocks as an example to describe how to use the checklist. ACD is a display for operational controllers at Terminal Radar Approach Control (TRACON) facilities to acquire the current traffic situation and control aircraft. The display contains a traffic situation area occupying the central part of the computer screen and a menu bar on the top of the screen. The traffic situation area graphically displays aircraft symbols and datablocks, superimposed with maps, sector boundaries, weather, and range rings. While controllers can adjust the background color of the screen at their own preference from complete dark to 60% blue, most controllers set their screen background very dark.

A datablock is composed of several short lines of text. Four text colors are used. White is used for datablocks of those aircraft owned by a controller; green is used for datablocks of aircraft that are not owned by the controller. Yellow is used for “point-out” datablocks. A “point-out” datablock means that a controller can point out a datablock that might be interesting to another controller by making the datablock yellow on the other controller's display. When an aircraft is in a potential conflict, the red alert text “CA” (Collision Alert) or “LA” (Low Altitude Alert) appears on the top of its datablock. The alert text blinks until the controller acknowledges it. The red text remains until the conflict is solved.

The red text “CA” or “LA” on the top of a datablock is intended to capture the controller’s immediate attention. Thus, we identified the purpose of the blinking red as *attention*. Here the colored target to be attended to is the red text, and the main distractors are green and white datablocks. Yellow datablocks are present only occasionally and momentarily, so they are not considered as major distractors. According to Table 1, three conditions have to be met for red to be effective in attention: 1) Luminance — the luminance of the red text is lower than the luminance of green and white datablocks, so the condition is not met; 2) luminance and chromaticity difference — the chromaticity differences between red and white is 0.29, and the difference between red and green is 0.36 (both are greater than 0.24), so the condition is met; and 3) number of distractor colors — There are two main distractor colors, white and green, so the condition is met. Each of the three conditions must be met for the color to be effective. These results are listed in Table 2.

Table 1: A checklist of the effectiveness of color use in ATC displays.

Task purpose	Color and visual factors	Conditions for color-use being effective	Yes / No
Attention	Luminance	The luminance of the color-coded target is greater than or equal to that of distractors (i.e., other materials displayed in the visual field).	
	Luminance and chromaticity	The luminance difference between the color-coded target and distractors is greater than 20cd/cm^2 regardless of the chromaticity difference. Alternatively, the chromaticity difference between the color-coded target and distractors should be greater than 0.24 in CIE chromaticity coordinates.	
	Number of distractor colors	The number of distractor colors should be less than 3~4 (The number of colors of the distractors with a size greater than or equivalent to that of the target should be minimized).	
Identification	Color naming	The colors used for identification can be named uniquely and consistently.	
	Chromaticity	The chromaticity differences between the colors are greater than 0.036.	
	Luminance	The luminance differences between colors are less than 20cd/cm^2.	
	Number of set colors	The number of colors is less than 7.	
Segmentation	Luminance or Chromaticity	For regional object segmentation, the chromaticity difference between the object and its surrounds is 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, is greater than ~5%. For pattern segmentation, the color difference between the pattern and its surrounds is greater than 0.02. Alternatively, the luminance ratio is greater than 15~20%.	
	Number of object colors	The number of colors of the object to be segmented is less than 2 unless the object is composed of a regularly patterned texture of different colors.	

The elements in Table 2, from left to right, are purpose of color use, conditions, and evaluation (Yes /No). Table 2 shows that one of the conditions for the purpose "Red for attention" is not met; we conclude that the red alert text is not effective for attention. In real operations, controllers typically rely on the blinking signal rather than the color to detect such alerts.

White, green, and yellow are to distinguish datablocks associated with owned, unowned, and pointed-out aircraft. The purpose of these colors is *identification*. In addition, the red alert text is also used to identify datablocks of aircraft in conflict after the blinking signal is stopped. According to Table 1, three conditions should be met for the colors to be effective in identification: 1) Color naming - the four colors are basic colors and can be named reliably, so the condition is met; 2) Chromaticity - the chromaticity difference of any pair of the four colors is greater than 0.036, so the condition is met; and 3) Number of colors - the number of colors for identification is four (less than seven), so the condition is met. These results are listed in Table 2. Overall, this set of colors is effective for identification since all the conditions are evaluated as "Yes."

Color and visual factors that negatively affect task performance

The previous section described the benefits of color use and how to achieve them. Unfortunately, the benefits of color use are often accompanied by some negative effects. We observed a number of situations where color use could be troublesome for task performance. Moreover, controllers and supervisors acknowledged that in some circumstances color use might have the potential of leading to operational errors. We identified and classified the cognitive and visual factors in those situations. In this section, we first describe some typical color factors that may negatively affect ATC task performance and provides a rationale for those factors based on the results of many visual studies in the literature. Next, we present a checklist of potential drawbacks of color use based on the factors and the rationale. Finally, we present an example of how to apply the checklist to ATC displays.

Negative factors

Distraction and inattentional blindness

Attention implies withdrawal from some information to effectively deal with other information. Since the human ability to attend to stimuli is limited, attending to a salient target in a complex scene acts as a distraction for other materials in the scene. Therefore, the perception of other stimuli is reduced. Hence, what facilitiates attention is also the source of distraction. In extreme circumstances, the pop-out of certain targets can induce a phenomenon known as "inattentional blindness," which means when observers focus their attention on a salient object, they often fail to notice other salient objects or events. An example in the ATC environment is the situation where a controller may fail to notice a blinking datablock that is being handed-off between sectors if a conflict alert occurs at the same time. The causes for inattentional blindness have been studied by many researchers. It was demonstrated that the sudden onset of color was capable of inducing inattentional blindness in visual displays (Schmidt, Vogel, Woodman, & Luck, 2002).

For ATC tasks, operational controllers need to be continuously aware of on-going information in the radar display. Stein (1992) reported that the best eye movement pattern for controllers was to scan the radar display continuously. However, the onset of color targets can interrupt the smooth scan and reduce controllers' awareness of the overall air traffic situation. DiVita, Obermayer, Nugent, and Linville (2004) reported that inattentional blindness negatively affected operators' task performance in detecting critical events on a combat information display and

Table 2: Evaluation of the effectiveness of color use in ACD datablocks

Purpose of color use	Conditions	Evaluation
Red for attention	Luminance	No
	Luminance and chromaticity difference	Yes
	Number of distractor colors	Yes
White, green, yellow, and red for identification	Color naming	Yes
	Chromaticity difference	Yes
	Number of colors	Yes

had the potential to cause performance errors. Therefore, the application of color for attention should be limited and done with caution. If other important changes may occur simultaneously with color onsets for attention, then additional redundant cues should be provided to controllers to ensure their situational awareness.

Uncertainty in identification

Christ (1975) reviewed color use in visual displays and concluded that the advantage of color could be significant only when color was highly correlated with the information it denoted; if color was only partially correlated with the content of information, then a user could not use color as the unique selection criterion for decision-making, and color had no advantage over achromatic attributes. For example, Jeffrey and Beck (1972) used color to encode types of aircraft in a simulated flightdeck display, and they had subjects identify potential conflicts between aircraft. However, they did not find any improvement in task performance. One reason was that each color represented multiple aircraft types with some common features, while subjects needed information about other features to perform the task. Moreover, such color-coding could cause performance errors because of the uncertainty it introduced. By the theory of signal detection, increasing uncertainty of the selection criterion leads to a higher probability of decision errors. In addition, it took users more time to identify targets with irrelevant color-coding.

Color-coding uncertainty occurs in some ATC displays. While manufacturers assume some selection criteria for controllers to perform tasks, controllers may use other criteria or break down the criteria in real operations. For example, some displays encode aircraft delay time by color, such as green for delays less than five minutes and yellow for longer delays ranging from 10 to 15 minutes. However, controllers need the precise time when dealing with aircraft delay. Here colors are only partially correlated with the delay time, and they cannot be used as the appropriate selection criterion for the task. In such cases, controllers tend to ignore colors. When asked about the meanings of colors, many controllers were not aware of the answers because "colors are of no use anyway." Nevertheless, even though controllers may ignore color-coding, colors still distract them during task performance.

Loss of integration

Color-coding has dual-effects on the information processing in the brain: integrating pieces of information with the same color and segregating information with different colors. Segregation and integration are like the opposite ends along an axis: A higher level of segregation is always accompanied with a lower level of integration, and vice versa. In particular, because color and achromatic signals are processed separately in the visual system, the brain has to make an extra effort to integrate information represented by color and achromatic attributes. Therefore, when using colors to categorize information, the brain tends to process different colors separately and is less likely to associate the pieces of information displayed in different colors. This can pose a risk to tasks in which different types of information have to be considered together simultaneously.

Next, we use an example to describe the potential risk of loss of integration due to color use in ATC displays. ACD displays use white to represent datablocks of aircraft owned by a controller and green for those not owned by the controller. This scheme could cause integration problems. In this particular example, the task of maintaining aircraft separation requires that information about owned and unowned aircraft be considered together to avoid confliction between them, especially for those aircraft near sector boundaries. However, the application of color weakens information integration of the two types of aircraft ownership. Thus, controllers may have a lowered probability of detecting potential conflicts between owned and unowned aircraft.

Color-coding interference

From the cognitive point of view, when people use color displays they build a mental model of the display in which colors are associated with certain categories of information. When several sets of color-coding are used in a display, users' cognitive workload is significantly increased due to switches between the coding schemes. Moreover, multiple color schemes often lead to the following situations: (a) one color has multiple meanings in a display; and (b) several colors are assigned the same meaning.

If the relationship between a color and the assigned information is not unique, then the mental model of color use could not be reliably established. Furthermore, different sets of color-coding may interfere with each other. Colors in one coding set become irrelevant to other sets and potentially harmful, as they can lead to an incorrect distraction for the task at hand. For instance, they can become detrimental to a search task if a lot of non-targets are in the target color (Poulton & Edwards, 1977). Therefore, errors may occur in the process of inferring the meanings of color. Many studies have demonstrated this contention. In particular, Yuditsky et al. (2002) tested color-coding of (a) aircraft destination airport, (b) overflights, and (c) special-use air space in an air traffic control display. The results showed that while each individual color-coding might improve controller performance and efficiency, there was no benefit when all three sets of color-codes were used.

Multiple color-coding is a common phenomenon in ATC displays. Perhaps due to the complex nature of ATC tasks, nearly all color displays use more than one set of color schemes. For example, red is used at least three times with different meanings in the Traffic Management Advisor to indicate: 1) aircraft delay time longer than 15 minutes; 2) rush time of an airport; and 3) the capacity boundary in the aircraft load graph. The problem is complicated by the fact that individual controllers usually work with multiple displays.

Figure 1 illustrates the confusing color-coding used in ATC displays. The information represents the analysis of color use in four displays in terminal facilities. Those include Standard Terminal Automation Replacement System (STARS), ACD, Traffic Management Advisor (TMA), and Integrated Terminal Weather System (ITWS). The upper, middle, and bottom panels correspond to *attention*, *identification,* and *segmentation,* respectively. The vertical axis represents the number of times that a color is used for a given purpose in the four displays. The horizontal axis represents colors. The top panel indicates that many colors are used for attention. Therefore, controllers cannot just rely on a single color to distinguish critical messages from non-critical ones. Furthermore, most basic colors are used for all three purposes. Notice that in the bottom panel four colors (red, green, yellow, and blue) are predominately used for segmentation, which introduces interference with the colors used for attention and the ones for identification. For example, red could mean a windshear warning, yet it could also mean nothing special. In such situations, controllers have to rely on additional visual features to identify critical information.

At present, we are not aware of any study that explored the maximum number of color schemes a user can process in a display. Fortunately, we informally collected some preliminary data from five controllers through the discussions conducted during our facility visits. We found that four of five controllers preferred no more than 2 or 3 color schemes in a display, and one controller did not express any preference. While it might be difficult for display designers to keep the rule of "one color for one meaning," a less-restricted compromise is that one color should be used for one type of task purpose: attention, identification, or segmentation. In particular, colors used for attention should not be used for segmentation.

Text readability

ATC tasks involve a great deal of text reading because text comprises a relatively large part of the materials presented on displays. Therefore, ATC operations require that text should be read effortlessly and in an error-free manner. A great deal of research studied text readability, which is the property that permits an observer to read text easily on a screen irrespective of meaning (Legge, Rubin, & Luebker, 1987). Readability is primarily determined by the luminance contrast between text and its background colors. Luminance contrast can be calculated as the luminance difference

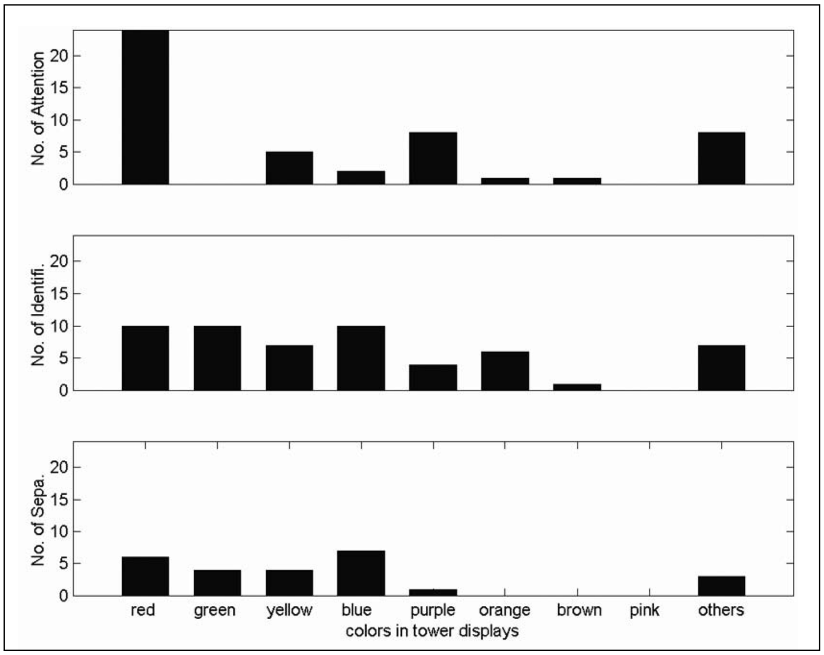

Figure 1: Number of times that each color is used in four terminal displays for a given type of task purposes. The top, middle, and bottom panels are for the purposes of attention, identification, and segmentation, respectively.

between the text and background divided by the sum of the luminance. Therefore, zero contrast means that the text and background have the same luminance, and 100% contrast means the maximum luminance contrast (the one produced by the combination of white and black). Several experimental studies demonstrated that readability decreases linearly with luminance contrast. Below 20~30% contrast, readability deteriorates significantly and decreases with contrast much more rapidly (Legge et al., 1987; Scharff & Ahumada, 2002). Thus, in industrial applications, a 20% to 30% luminance contrast is often taken as the threshold contrast for text reading. Furthermore, Krebs, Xing, and Ahumada (2002) found that the minimum text size for error-free reading varied with contrast when the contrast was less than 20%; the minimum size was a constant for a given monitor within the contrast range of 20-100%.

Coloring text can degrade text reading. Color use can result in low text readability. When people choose colors for text, they are typically concerned with the chromaticity, not the luminance of a color. For instance, we observed some situations where the background of a text box was highlighted with color to indicate a different status of the text; however, the luminance of the highlighting colors was very close to that of the text, so users experienced difficulty in reading the text.

Below are some sample combinations of text and background colors in ATC displays that result in low text readability:

Red vs. black
Yellow vs. white
Yellow vs. green
Green vs. cyan
Blue vs. brown
Gray vs. green
Gray vs. cyan
Orange vs. green

Text readability can be assessed by determining the luminance of text and background colors. Appendix B in this report describes how to calculate luminance from the *rgb* values of a color, where *r, g,* and *b* are the digital values for the phosphor channels (red, green, and blue) of a computer display to generate a color. If the monitor parameters of color calibration are not available, luminance can be estimated with the following equation: $Lum = (L_r * r/255)^{gamma} + (L_g * g/255)^{gamma} + (L_b * b/255)^{gamma}$, where L_r, L_g, and L_b are the maximum luminance for the red, green, and blue channels, i.e., the luminance measured at *rgb* values: (255, 0, 0), (0 255, 0), and (0, 0, 255). The typical default values are $L_r = 21.3389$, $L_g = 70.6743$, and $L_b = 7.98680$. The parameter *gamma* describes the nonlinearity of luminance response for a given monitor. It typically varies from1.8 to 2.5 for most monitors with a default value of 2.2 (Berns, 2000). We calculated the contrasts for the text-background combinations of 14 colors that are frequently used in ATC displays. Appendix B describes the calculation method, *rgb* values of the colors, and the calculated luminance contrasts.

Experience interference

Imagine that you see a set of words of color names printed in different colors. For example, the word "red" is printed in green ink, and the word "green" is printed in yellow ink. When you look at one of the words, you see both its *color* and its *meaning* (from experience). If those two pieces of information conflict, you have to make a choice.

The meaning attached to a word or color is learned through experience. Since access to word meaning becomes automatic and effortless (Stroop, 1935), when meanings of the word and color come into conflict, interference occurs even when one tries to pay attention to colors. This effect can result in misinterpretation of color-coded information. Thus, such interference should be avoided in visual displays.

There are some general conventions about color use in ATC displays, and controllers have acquired those conventions through experience. If a color use conflicts with the conventions, what is in the experience and the perceived information may interfere with each other, and the perceived information can be biased by experience. For example, red is usually the top choice to convey warning and alert messages. Controllers would naturally infer that a red code conveys urgent information, and the attention to red reduces awareness of other information. Problems arise when the color is used to encode an aircraft's destination even though the destination of that aircraft is no more important than that of any other aircraft. When two meanings are associated with the same color code (e.g. urgency, destination), the brain has to exert extra effort to suppress one meaning to correctly interpret the meaning of that code. During our discussions at the ATC facilities, some controllers complained that such color-coding did not help their tasks at all but added distraction. Generally speaking, when designing a new ATC display, color schemes should follow the conventions so that color use is compatible across all displays in the ATC environment. As Cardosi (2003) pointed out, compatibility is crucial between new and existing ATC tools for controllers to adapt to a new tool. For more information about color use conventions, a good reference is the color use guidelines of ATC displays developed by Cardosi and Hannon (1999).

The following instance demonstrates the importance of compatibility between color schemes and experience. We observed an interesting way that controllers used Remote-ACDs in air traffic control towers. Remote-ACD offers two versions: The nighttime version uses the same color schemes as those used in ACDs (with a dark background); the daytime version has a bright blue background, and some colors are different from those in the nighttime version. Theoretically, the daytime version suits the eyes better for daytime illumination. However, we observed that controllers chose to use the nighttime version even during the daytime because "the colors in the nighttime version look natural" (quoted from several controllers). "Look natural" implies that the color scheme is more consistent with controllers' experience.

Below is a list of some color use conventions that we observed in current ATC displays:

- Red for warning and alert;
- Yellow and orange-red for messages that need some attention but not as urgent as those in red;
- Green and white for normal status;
- Dark blue or black for background.

Color-naming inconsistence

Human eyes can identify at least a million possible color samples, no two of which would match if placed side by side and viewed in a normal viewing condition. However, certainly there are not as many color names. Human categorizes colors using a limited number of names. The criteria for color categorization vary among people between and within cultures. The majority of distinguishable colors could be named differently across people, except for the 11 basic colors (red, green, blue, yellow, purple, orange, pink, brown, black, white, gray) that can be named easily and consistently (Boynton & Olson, 1990). Therefore, the manipulation of the consistency of color-naming may change performance in tasks where categorization and identification by color name are important. Indeed, Guest and Van Larr (2002) found that highly "nameable" color led to better performance in identification tasks than metrically equivalent but less categorically distinct color sets when they measured response times, confidence ratings, and response accuracy. Another concern is that color-naming inconsistency may negatively affect the communication of color-coded information in controller teamwork.

Throughout our facility visits, we identified many situations where a color was named differently by controllers. For instance, the graphical tool in DSR provides four colors for controllers to use. We asked controllers and supervisors to name these colors at all the three En Route facilities we visited. The colors were named inconsistently among the staff within and between facilities. For example, one of the colors was named red, pink, white-red, or reddish pink. Another color was named green, yellow, or yellowish green. However, the good news is that for all such cases we identified, controllers acknowledged that inconsistent color-naming was not a problem for them. While they used colors to perform tasks, they exchanged information by the operational meanings of colors, not color names per se. Nevertheless, inconsistent color-naming has the potential to cause communication errors. That is not desired for ATC tasks, especially those involving attention capture and identification.

View-angle intolerance

In recent years, the FAA has begun to replace the older CRT monitors with new LCD monitors. Unfortunately, a common problem with LCD monitors is their view angle intolerance. That is, due to the nature of liquid crystal molecules, polarized light entering a liquid crystal material off axis is treated differently than light entering along the optical axis. The electrooptic transfer function of LCDs tends to be angular-dependent. In addition, liquid crystal molecules operate differently on different wavelengths of light when responding to off-axis light, so different view angles cause significant variations in displayed colors, and colors are usually washed off toward white if viewed from large off-axis angles. Therefore, when viewed from off-axis angles, text and graphs displayed on LCDs have a loss of luminance contrast and undesirable variations in hue. This can be seen from the example in Figure 2.

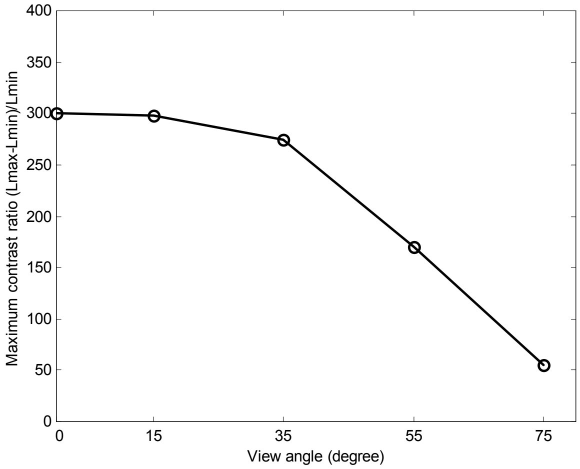

Figure 2: View angle intolerance of a General Digital monitor. The horizontal axis is view angle, and the vertical axis is the maximum contrast ratio, calculated as (Lmax-Lmin)/Lmin, where Lmax and Lmin are the maximum and minimum luminance for a color measured from a given view angle.

Figure 2 illustrates the view-angle dependence of displayed colors for a General Digital monitor that is currently used in many ATC facilities. The horizontal axis represents the view angle, and the vertical axis represents the luminance contrast of colors. The result indicates that the contrast decreased rapidly as the view angle increased beyond 35 degrees, implying that target detection, discrimination, and text reading at large view angles could be very difficult.

View-angle intolerance can be a potential problem for controllers using color displays. The following two situations are typical in ATC facilities: 1) One controller uses several computer monitors, and some monitors have to be viewed from off-axis angles. In particular, tower controllers spend a significant time looking out of the window and need to walk around frequently, so it is inevitable for them to view displays from off-axis angles. 2) Two or more controllers share the same monitor. ATC tasks often require teamwork. In particular, in Centers two controllers (referred as R-side and D-side) usually work together. While the R-side controller sits in front of the radar display, the D-side controller, whose typical view angle to the display is about 45-60 degrees, also needs to acquire information from the radar display. We noticed in the facilities that controllers tried to solve the view-angle problem by turning the monitor back and forth between them. When asked why they were turning the monitor around, controllers stated that they might miss crucial information due to off-axis view angles.

A checklist of color-use drawbacks

We developed a checklist to summarize the drawback factors described in this section, as shown in Table 3. The first column of the table lists the pertinent perceptual and cognitive issues involved in color use. The second column lists the color and visual factors associated with the issues. The third column lists some possible consequences associated with the factors. The last column consists of checkboxes that can be filled with "yes" if a factor described in the second column is involved in the use of color and "no" otherwise. This checklist and the checklist of color effectiveness in Table 1 provide a method for a quick evaluation of color use in ATC displays.

An application example of the checklist

Once again, we use the color scheme of ACD datablocks as an example to describe how to apply the checklist. Among the drawback factors listed in Table 3, the first six evaluate individual color. For each color used in ACD datablocks, we evaluated the first six factors and classified the result as "Yes" or "No." "Yes" means that the drawback factor exists, so the color usage has the potential of negatively affecting task performance; "No" means that the factor does not exist for the given color usage. In addition, we used "NA" to refer to situations where a drawback factor is not applicable to the color usage. The evaluation results are presented in Table 4. The order of the elements in the table (from left to right) is color, purpose, and six drawback factors. We used the following symbols to represent the six factors: "dis" for distraction, "unc" for coding uncertainty, "int" for loss of integration, "mul" for multiple color schemes, "read" for text readability, and "exp" for experience interference. In the column "task purpose," we also used "Att" for attetnion, "Iden" for identification, and "Seg" for segmentation. Each row in the table is for one color usage. Next, we describe the evaluation of every color usage in ACD datablocks.

As mentioned earlier, ACD datablocks use blinking red text for alerts. They also use white, green, yellow, and non-blinking red to distinguish different types of aircraft.

Drawbacks for using blinking red:

- *Distraction.* When the red alert text blinks and captures a controller's attention, the controller may miss other salient visual stimuli occurring at the same time, such as a blinking datablock that indicates an aircraft handing-off. Therefore, the factor is evaluated as "Yes."
- *Coding uncertainty.* Red is precisely correlated with the meaning "alert." The factor is thus evaluated as "No."
- *Loss of integration.* The datablocks of all the aircraft that are under conflict are indicated with the same red color, so there is no loss of integration. The factor is evaluated as "No."
- *Multiple coding.* Red is only used for the alert text in ACDs, so the factor is "No."
- *Text readability.* The luminance contrast between the red text and the dark background is about 11%, less than the threshold (20%) contrast for error-free reading. Thus, the factor is evaluated as "Yes."
- *Experience interference.* The use of red in alert texts is consistent with the color use convention that red is reserved for alert or emergent information. The factor is thus evaluated as "No."

To avoid tedious description, we will only describe the factors evaluated as "yes" for non-blinking red, white, green, and yellow. Non-blinking red has one drawback: It results in low text readability on a dark background. White is used to distinguish datablocks of owned aircraft from green datablocks of unowned aircraft. It has two potential drawbacks: distraction and loss of integration. Since white datablocks are much brighter than green datablocks, they automatically draw controllers' attention,

Table 3: A checklist of potential drawbacks of color use in ATC displays.

Perceptual and cognitive issues	Color and visual factors	Possible consequences	Yes / No
Distraction	Multiple colored targets for attention are onset simultaneously within the view field.	Only one of the targets captures attention; others could be ignored.	
Coding uncertainty	Messages (text or symbols) identified by colors do not have a unique meaning; thus, color cannot serve as the selection criteria.	Slower and less accurate in identification compared to using text or symbols alone.	
Loss of integration	Color-segmented messages need to be considered together simultaneously for task performance.	Less chance to associate pieces of information that are color segmented.	
Multiple color schemes	1) More than 3 sets of color-coding in a display.	Increasing chances of missing information; users tend to ignore color-coding.	
	2) One color is used for multiple purposes, or multiple colors are used for the same purpose.	Increasing cognitive workload; slower in interpreting information; increasing chances of misinterpreting information.	
Experience interference	Color use differs from controllers' experience (such as red for non-critical information).	Increasing chances of misinterpreting information.	
Text readability	The luminance contrast between the text and background colors is less than the threshold contrast (20~30%) for error-free reading.	Reducing reading speed; increasing reading errors.	
Color-naming consistence	Color cannot be named consistently among users.	Increasing communication difficulty in teamwork.	
View-angle intolerance	Hue and luminance contrast of colors are largely washed off when viewed from large off-axis angles in LCD monitors.	Color-coding becomes ineffective.	

Table 4: Evaluation of potential drawbacks of color use in ACD datablocks.

Color	Purpose	dis	unc	int	mul	exp	read
Blinking red	Attention	Yes	No	No	No	No	Yes
white	Identification	Yes	No	Yes	No	No	No
green	Identification	No	No	No	No	No	No
yellow	Identification	Yes	No	Yes	No	No	No
red	Identification	No	No	No	No	No	Yes

“dis” distraction ; “unc” coding uncertainty ; “int” loss of integration; “mul” multiple color schemes; “read” text readability; “exp” experience interference.

which decreases their perception of datablocks in other colors. Moreover, green and white colors segregate the owned and unowned aircraft in a controller’s mental representation of the traffic situation. Hence, the integration between owned and unowned aircraft is reduced. However, ATC tasks require controllers to consider owned and unowned aircraft together to ensure aircraft separation. This is especially important for those aircraft near sector boundaries. Due to the color-coding, controllers are less likely to detect conflicts between owned and unowned of aircraft. Therefore, application of the white color to owned datablocks has the potential to cause performance errors. The evaluation of yellow is the same as that for white, as described above. Fortunately, in ATC operations, yellow is used infrequently and momentarily, so the operational effect of the two drawback factors associated with yellow may not be as severe as that associated with white.

DISCUSSION

In this report, we described the benefits of color use in ATC displays. We also derived a rationale for how to achieve these benefits based on accumulated vision and cognitive research. We also identified several drawbacks of color use in ATC displays and presented the potential consequences of inappropriate use of colors in the domain of perceptual and cognitive information processing. While systematic data were not available from our limited facility visits, those drawbacks were commonly observed in the ATC facilities. Also included in the report are two checklists that we developed to evaluate color use in ATC displays: “A checklist for color-use effectiveness” and “A checklist of color-use drawbacks.” The first checklist was intended to address the concern, “Can the use of color achieve the intended task purposes?” The second checklist was designed to answer the question, “May the use of color on ATC displays introduce any risk to task performance?” While these two lists may not cover all color factors, they are pertinent to ATC displays, so they can serve as a baseline to qualify the use of color in ATC. Manufacturers and human factors practitioners are encouraged to use these checklists in interface design and acquisition evaluation of ATC displays. The checklists should also be applied to the process of customizing color schemes of some ATC products for given facilities.

Subjective vs. objective assessment of the usefulness of colors

Color is something that everyone with normal color vision can perceive easily. Unfortunately, the neural mechanisms of color processing are not readily apparent. In many ways, the brain processes color information differently from the physical properties of color. For example, the neurons in the visual system respond monotonically to the increasing of luminance, so the brain encodes luminance information in a similar way as we see it. However, although colors can also be described as continuous variables along chromaticity coordinates, researchers have failed to find neural mechanisms that would encode continuous chromaticity variables. Hence, it is not surprising that subjective opinions about the effect of color can sometimes be quite different from (or even opposite to) objective assessments.

One reason for using colors in displays is that users prefer them, despite their being remarkably inaccurate in task performance, compared with their performance using achromatic displays (Narborough-Hall, 1985). In fact, several studies showed that the use of colors made subjects’ tasks somewhat easier but not more effective (Christ, 1975). Sometimes, subjects feel more secure with color-coding. While no significant differences in response latencies to colored or achromatic displays (alphanumeric and graphic) were found, subjects reported greater satisfaction with colored displays (Tullis, 1981). Moreover, other experiments demonstrated that, while subjects believed that color improved their ability to detect details, color did not improve target detection or identification (Jeffrey & Beck, 1972). Hence, subjective assessments of the effect of color use are not sufficient for assessing displays of human-computer automation systems.

The more color, the better?

A trend in ATC displays is that more colors are being used in newly developed displays. For example, the Standard Terminal Automation Replacement System is a newer radar display for terminal facilities. It uses more colors than the ACD that was developed earlier. Another trend is that colors are being added to existing displays. For example, a magenta box was added to a part of the datablock on En Route radar displays. There seems to be a general belief that more colors lead to more efficient information processing. However, that is not always true. While we showed that several factors contributed to advantages of color use for each task purpose (*attention, identification, and segmentation*), a common factor for all the three task purposes is that the effectiveness of color use deteriorates with an increase of the number of colors on a display, as described in Table 1. Moreover, color use has some inevitable disadvantages, such as reducing text readability and increasing visual fatigue. Therefore, we suggest that color use in ATC displays should be limited, and a color should be used only when it is proven to 1) benefit task performance and 2) have no significant disadvantage on task performance.

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APPENDIX A:
CIE (INTERNATIONAL COMMITTEE OF ILLUMINATION) COLOR COORDINATES

A computer monitor generates a color through three phosphor channels: red, green, and blue. The amount of phosphors emitted from a channel is specified with 8-bit digital values of the channels: *r, g*, and *b*, each for red, green, and blue phosphors. Computer programmers use these three numbers to specify a color on displays. For example, *rgb* values of (255, 0, 0) are for red, and (255, 255, 0) are for yellow. While *rgb* values specify the physical attributes of a color on a monitor, they do not tell how viewers perceive the color.

The International Committee of Illumination (CIE) defined color chromaticity coordinates to describe human color perception. In this definition, a color can be specified by three variables: *L, x,* and *y,* where *L* is the luminance of a color while *x* and *y* determine the hue. *x* and *y* vary between 0 and 1. For example, the typical values for white in a computer monitor are x=0.3300 and y=0.3515; the values for red are x=0.6340 and y=0.3337. The *xyL* values of a color surface can be measured with a colorimeter.

The relationship between *rgb* and *xyL* values can be specified with a nonlinear transformation and a linear matrix transformation, as described by the following equations:

$R=(r/255)^{\text{gamma}}$
$G=(g/255)^{\text{gamma}}$
$B=(b/255)^{\text{gamma}}$

Where the parameter *gamma* describes the nonlinearity of luminance response for a given monitor. It usually varies in a range of 1.8-2.5 for CRT monitors, with a typical default value of 2.2. The transformation between RGB values and CIE chromaticity coordinates (*xyL*) are determined by the following equations:

$X=40.9568*R + 35.5041*G + 17.9167*B;$
$Y=21.3389*R + 70.6743*G + 7.98680*B;$
$Z=1.86297*R + 11.4620*G + 91.2367*B;$
And,
$x=X/(X+Y+Z)$
$y=Y/(X+Y+Z)$
$L=Y$

Notice that the parameters in these transformations vary from monitor to monitor. The parameter values used here are typical default values for CRT displays. The process of determining the parameters of the transformations for a given monitor is called color calibration.

One of the greatest disadvantages of the CIE chromaticity systems is that visually they are not spaced equally. Thus, distortions occur in attempting to relate perceived colors to locations of the CIE chromaticity diagram. Based on the *xyL* systems, the CIE adopted the *Lu′v′* coordinates that were more nearly uniformly spaced with respect to color perception. Therefore, the chromaticity difference between two colors can be computed as $((\Delta u')^2 + (\Delta v')^2)^{1/2}$. The values of *u′* and *v′* can be computed from *x* and *y* through two non-linear equations:

$u' = 4x / (-2x+12y+3)$
$v' = 9y / (-2x+12y+3)$

APPENDIX B:
CALCULATION OF TEXT READABILITY ON VISUAL DISPLAYS

Text readability is determined by luminance contrast of the text and background colors. The contrast threshold for error-free reading is typically taken as 20~30%.

1. Definition of contrast

Without specified otherwise, when text contrast is mentioned in the literature, it means the Michelson contrast, defined as $(L_t - L_b) / (L_t + L_b)$, where L_t is the text luminance and L_b is the background luminance. The contrast varies between 0 and 1.

2. Color specification

Here lists the typical *rgb* values of 14 frequently used colors. Notice that the values used in ATC displays for these colors may vary slightly, depending on manufacturers and monitors.

Red:..................... (255 0 0)
Green:.................. (0 255 0)
Yellow .... (255 255 0)
Blue: .... (0 0 255)
Purple: .... (102 0 153)
Brown .... (153 75 0)
Orange .... (255 165 0)
Pink .... (255 192 203)
Cyan .... (0 255 255)
Magenta .... (255 0 255)
Black .... (25 25 25)
White .... (255 255 255)
Medium gray ...... (192 192 192)
Yellowish green .... (153 204 51)

3. Luminance computation

The luminance of a color can be computed with the following equation:

$\mathrm{Lum}= (L_r *r/255)^{\mathrm{gamma}} + (L_g *g/255)^{\mathrm{gamma}} + (L_b *b/255)^{\mathrm{gamma}}$,

Where L_r, L_g, and L_b are luminance measured at *rgb* values: (255, 0, 0), (0 255, 0), and (0, 0, 255). *gamma* is the non-linearity parameter of a monitor. These parameters vary from monitor to monitor. We used the following default values:

$L_r = 21.3389$
$L_g =70.6743$
$L_b =7.98680$
gamma= 2.2

Table B-1 shows the calculated contrasts (in percentages) for all the text-background combinations of the 14 colors. When both the text and background luminance are less than 10 cd/cd^2, the contrast was trimmed to zero because those combinations produce very low readability.

Table B-1: Estimated text contrast for 14 color combinations.

	Red	Gre	Yel	Blue	Pur	Bro	Oran	Pink	Cyan	Mag	Black	White	Gray	YG
Red	0	53	62	45	59	29	38	49	57	15	76	64	43	40
Green	53	0	13	79	85	71	18	4	5	41	92	17	13	16
Yellow	62	13	0	84	88	77	30	17	7	51	94	4	26	29
Blue	45	79	84	0	0	0	71	77	81	57	0	85	74	72
Purple	59	85	88	0	0	0	79	84	87	68	0	89	81	80
Brown	29	71	77	0	0	0	61	69	74	42	0	79	64	62
Orange	38	18	30	71	79	61	0	13	23	24	89	34	5	1
Pink	49	4	17	77	84	69	13	0	10	37	91	21	8	11
Cyan	57	5	7	81	87	74	23	10	0	45	93	11	18	21
Magenta	15	41	51	57	68	42	24	37	45	0	82	54	29	26
Black	76	92	94	0	0	0	89	91	93	82	0	94	90	89
White	64	17	4	85	89	79	34	21	11	54	94	0	30	32
Gray	43	13	26	74	81	64	5	8	18	29	90	30	0	3
Yellow-green	40	16	29	72	80	62	1	11	21	26	89	32	3	0