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Color Analysis in Air Traffic Control Displays, Part II. Auxiliary Displays

Jing Xing
Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

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16. Abstract

This report presents the second part of our analysis of color use in Air Traffic Control displays. Part I of the study focused on operational displays, while this investigation focuses on auxiliary information displays with which controllers acquire additional information to make decisions. We chose three frequently used decision-support displays for the analysis. Those are: User Request Evaluation Tool (URET), Traffic Management Advisor (TMA), and Integrated Terminal Weather System (ITWS). For each display, we documented the background and default colors, color-coding, color usage, associated purposes of color use, and color complexity. With this systematic documentation, we were able to assess compatibility across displays. Using the color checklists we developed earlier, we also analyzed the effectiveness and shortcomings of color use in these displays. The results revealed a number of instances where the use of color might not be effective for its given purpose and where a color could have potential negative effects on task performance. The results of this study can benefit design prototypes and acquisition evaluation for new Air Traffic Control technologies.

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Color Analysis in Air Traffic Control Displays, Part II. Auxiliary Displays

INTRODUCTION

In our companion report "Color analysis in air traffic control displays, Part I. Radar displays" (Xing, 2006a), we documented and analyzed color in three operational displays: Automated Radar Terminal System Color Display (ACD), Standard Terminal Automation Replacement System (STARS), and Display System Replacement (DSR). While operational controllers primarily use radar displays to assist them in controlling traffic, they also frequently acquire information from auxiliary displays. For example, an en route controller needs to be aware of potential conflicts of aircraft in the near future and resolve them ahead of time. Instead of generating a complicated mental computation to figure out potential conflicts, the controller can use a User Request Evaluation Tool (URET) that displays the status of aircraft potential conflicts in different colors. Since such tools are intended to assist controllers' work, it is critical that the tools present information in a consistent (or at least compatible) manner with the information presented in the radar displays (Cardosi, 2003). However, the compatibility between the ATC displays has not received sufficient attention from the developers of ATC technologies, partly because there is a lack of systematic documentation of display specifications. Developers often fail to identify the colors used in other ATC displays. Therefore, one purpose of this study was to introduce a method for developers to document the use of color to improve the compatibility of ATC technologies.

Previously, we conducted a series of facility observations of color use in ATC displays (Xing & Schroeder, 2006). We found that most decision-support tools used colors more extensively than the radar displays. In general, decision-support tools used a large number of colors that did not comply with the human factors guidelines for the use of color in visual displays (Cardosi & Hannon, 1999; HF-STD-001, 2003). As a result, some colors are not effective for the given tasks, providing limited support for decision-making. Even worse, some color uses have the potential to negatively affect controllers' task performance. In addition, there appears to be discrepancies between what the developers wanted to convey by color-coding and what the controllers perceived. During our facility observations, we observed circumstances where controllers did not know or remember the meanings of colors in the decision-support displays. Therefore, another purpose of this study was to establish an example for developers to self-evaluate the use of color to improve the usefulness of their ATC tools.

While there are only a few types of radar displays, there is considerable variation in decision-support tools across ATC facilities. Moreover, some auxiliary displays allow controllers to set up color schemes based on their own preference. Thus, this report was not intended to cover the majority of decision-support tools. Instead, we chose several representative tools currently used in en route and terminal facilities for color documentation and analysis. Those are:

- User Request Evaluation Tool (URET) — URET is a major support display implemented in the en route facilities with the removal of flight progress strips.
- Traffic Management Advisor (TMA) — TMA is another auxiliary display used in en route facilities.
- Integrated Terminal Weather System (ITWS) — ITWS is a major weather display in terminal facilities. Since ITWS integrates many weather products, some parts of its color schemes are also used in other weather products such as Weather System Processor and Terminal Doppler Weather Radar (TDWR).

This study was intended to achieve two goals: 1) to analyze the benefits and drawbacks of color use in several representative auxiliary displays; and 2) to provide a systematic documentation of color use in those displays. For each of the three displays, this report presents information about color usage, the effectiveness of color use for given tasks, the potential drawbacks of color use, and the overall color complexity of the display.

METHODS

The methods are essentially the same as those used in the companion paper (Xing, 2006a). In brief, we applied the two color-use checklists developed by Xing (2006b) to assess the colors used in the three displays. The companion paper provided the two checklists in its Appendices. For each display, we first analyzed the use of color in individual functional components (such as datablock, menu, list, and maps). The analysis includes the task purpose associated with a color, the effectiveness of the color for the task purpose, and six potential drawback factors that may negatively affect task performance.

Previous work classified three categories of purposes associated with color use in ATC displays: 1) draw attention to critical events; 2) identify categories of information; and 3) segment complex scenes. We referred to those purposes as *attention, identification,* and *segmentation* (Xing & Schroeder, 2006). In addition to these purposes, each display has a background color and one or several "default" colors that are used to depict information in its normal status. We classified the effectiveness of color use into three categories: "E," effective for the given task purpose; "NE", not effective for the task purpose; and "D," effectiveness of color use depends on other visual attributes.

The six potential drawback factors can be briefly described as the follows: 1) *Distraction*: Multiple colored objects for attention are simultaneously presented within the visual field. 2) *Coding uncertainty*: Messages (text or symbols) identified by colors do not have a unique meaning in identification tasks. 3) *Loss of integration*: Messages in different colors need to be considered together simultaneously for successful task performance. 4) *Multiple color schemes*: One color is used for multiple purposes or multiple colors represent the same meaning. 5) *Experience interference*: Color use is against controllers' experience, such as red for non-critical information, or dark colors for critical information. 6) *Text readability*: The luminance contrast between text and background colors is less than the threshold contrast (typically taken as 20%) for error-free reading. These six factors were examined for each color use and the results were classified as either "Y" or "No." "Y" means that the drawback factor exists; thus, the color usage has the potential to negatively affect task performance. "No" means that the factor does not exist for the given color usage.

We then document the general information including background colors, default colors, and color complexity. The complexity is composed of three metrics: the total number of colors in the display (excluding the background color), the total number of colors used for identification, and the number of sets of color coding, where each set of colors is used to identify different aspects of the data.

RESULTS

This section includes two parts: The first part describes the color documentation and analysis for each ATC display. For each display, we briefly described color usage for each functional component, pointed out the situations where color use was not effective or had potential drawbacks, and analyzed color complexity. The results for each display are presented in a summary table. The second part provides a comparison of color use across displays.

User Request Evaluation Tool (URET)

URET is a tool that supports decision-making for en route controllers. A URET display is organized into seven windows. The main page has a black background and contains only a toolbar of buttons for window selection. The text of selection buttons is white. Since controllers frequently use only three of the seven windows (Aircraft List, Graphic Display, and Plans Display), we analyzed color use for these three windows.

Aircraft list

The aircraft list window has a horizontal title bar across the window on the upper portion and several lists occupying the majority of the window. The title bar text is black, and the background is filled with a bright cyan color. It is so salient that it can distract a user's attention from other materials in the window. However, this bar contains little information and does not require the controller's attention.

The aircraft list displays several types of text information. The elements in the list (from left to right) are flight status, flight ID, altitude, and routes. The background color of the list is black. The default text color is white. Flight status is indicated with text boxes in three columns. The frames of the boxes are white lines, and the texts are color-coded with red / muted red, yellow / muted yellow, cyan, and brown. Muted red and muted yellow have the same chromaticity as red and yellow, respectively. However, the luminance is lower for the muted colors. A flight in normal status is shown as a white box frame without any text in it. When a loss of separation is predicted, the box frame in the left-most column turns red or muted red, and a letter "R" is displayed in the box. The text matches the color of the box frame. Red represents predicted loss of separation within 5 miles. Therefore, red represents an alert that requires the controllers' attention. Muted red represents that the aircraft is not on its original flight plan and will develop a loss of separation if the controller takes some expected action. In the second column, yellow represents potential conflicts between aircraft predicted to come within 5-12 miles of each other, while muted yellow represents that a loss of separation within 5-12 miles will develop if the controller takes some expected action. The cyan color in the third column of boxes indicates aircraft that are predicted to conflict with a restricted airspace. There can also be numbers in the boxes to indicate the number of aircraft involved. The brown color appears in all three columns for a flight that has no tracking data; thus, auto-prediction is not available. The brown boxes are accompanied with a symbol "X" in them. Each of these colors has a different meaning, and controllers have to associate the colors with their meanings. Therefore, we classified the purposes of these colors as identification.

The text in the Flight ID list is white for normal flights, brown for flights without tracking data, and orange for overdue flights. The Flight altitude list uses white text for filed altitude and yellow text for changed altitude. Route information is displayed with texts in two colors for segmentation. However, because controllers are required to read the text to acquire information, the meaning of the colors is not significant to them.

Red and muted red are used for attention and identification. The low luminance of the red letter "R" and the frame of the text box are not salient enough to draw attention. As for identification, while red can effectively identify the aircraft status from those in white and brown, it cannot effectively identify the status from the ones in muted red. Thus, a user may encounter difficulties in differentiating aircraft status coded in red and muted red just based on the luminance difference between them. The same is true for yellow and muted yellow. In addition, the text readability for red, muted red, and muted yellow is low. Yellow is used for potential conflict in Flight Status and for changed altitude in the Altitude column; thus, the color has multiple meanings.

Graphic display

The graphic display illustrates datablocks and routes, special airport codes, and restricted airspace for aircraft on a 2-dimensional map. The color scheme of datablocks and routes is consistent with that used in the aircraft list. White datablocks and routes mean normal. Red, muted red, yellow, muted yellow, and cyan have the same meanings as those in the aircraft list. The drawbacks of color use are the same as those in aircraft list, except that red might be effective for attention in this window, depending on the line lengths of routes. We classified the effectiveness as "D."

Plans display

The plans display shows text information about the flight plan evaluation. Green text represents no conflict while red text is used to show a conflict. Both colors are for identification. The colors are effective for this purpose. A drawback is that the readability of the red text is low.

General information

A good color strategy in URET is that color schemes across individual functional windows are consistent. The same color is used in all the windows for the same task purpose and with the same meanings. For instance, blue is used as the background color of menu bars in all the three functional windows and the main page. Thus, the use of blue is counted as one although it appears four times. The background color is always black. The background of menu bars in all the windows is blue. The default text color is white for black and blue backgrounds and black on the cyan background of title bars. Nine colors are used in URET. The number of color uses is 16. Six sets of color-coding are used for identification. Among the colors, cyan and yellow encode multiple types of information.

The results of color analysis in URET are summarized in Table 1. The order of the elements in the table (from left to right) is components, color, color usage, task purpose, effectiveness, 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, "Exp" for experience interference, and "Read" for text readability. In the "task purpose" column, we used "Att" for Attention, "Iden" for Identification, and "Seg" for Segmentation. The overall color use information in URET, (listed in the bottom portion of Table 1) includes background colors, default colors, and the three metrics of color complexity (i.e., sets of color-coding, number of colors, and number of color usage).

Traffic Management Advisor (TMA)

TMA is a support display used in both en route and terminal facilities. The display provides a number of graphical components to improve users' situational awareness. The graphical components deployed at ATC facilities include timeline and load graphs. Like URET, the main page of TMA only contains a menu bar. Each component can be displayed in a window by clicking the selection buttons on the bar. Table 2 shows the summary results of color analysis for TMA.

Timeline

The timeline displays text about time axis, aircraft tag, tracking symbol, and delay time along a vertical axis indicating time. The background color of the Timeline window is black. The default color is white for the time axis. An aircraft tag may appear in one of three colors: green for normal arrival, yellow for unfrozen scheduled time of arrivals (STAs), and turquoise for frozen STAs. A frozen STA means that the aircraft is close enough to the meter fix that the time of arrival will not be changed except in response to extraordinary events. An unfrozen STA means that TMA schedulers can change the displayed STA. A tracking symbol composed of a small arrow and a short line connects every aircraft tag to the time axis. Each symbol is in the same color as the aircraft tag it connects unless TMA has not received any radar tracks

Table 1. URET color documentation and analysis

Window	Component	Color	Usage	Purpose	Eff	Drawback factors					
						Dis	Unc	Int	Mul	Exp	Read
Main window	Background	Black	Filled screen	NA	NA	NA	NA	NA	NA	No	NA
	Menu bar background	Blue	Filled bar	Seg	E	No	No	No	No	No	NA
	Menu bar text	White	Text	Default	NA	No	No	No	No	No	No
Aircraft list	Background	Black	Filled screen	NA	NA	NA	NA	NA	NA	No	NA
	Menu bar background	Blue	Field bar	Seg	E	No	No	No	No	No	NA
	Menu bar text	White	Text	Default	NA	No	No	No	No	No	No
	Title bar background	Cyan	Filled bar	Seg	E	Y	No	No	No	No	No
	Title bar text	Black	Ttext	Default	NA	No	No	No	No	No	No
	Frames of list	White	Lines	Default	NA	No	No	No	No	No	NA
	Flight status	White	Text	Default	NA	No	No	No	No	No	No
		Red	Text	Att	NE	No	No	No	No	No	Y
				Iden	NE						
		Muted red	Text	Iden	NE	No	Y	No	No	No	Y
		Yellow	Text	Iden	NE	No	No	No	Y	No	No
		Muted yellow	Text	Iden	NE	No	Y	No	No	No	Y
		Cyan	Text	Iden	E	No	No	No	Y	No	No
		Brown	Text	Iden	E	No	No	No	No	No	NA
	Flight ID	White	Text	Default	NA	No	No	No	No	No	No
		Orange	Text	Iden	E	No	No	No	No	No	No
		Brown	Text	Iden	E	No	No	No	No	No	No
	Altitude	White	Text	Default	NA	No	No	No	No	No	No
		Yellow	Text	Iden	E	No	No	No	Y	No	No
	Route	White	Text	Default	NA	No	No	No	No	No	No
		Cyan	Text	Seg	E	No	No	No	Y	No	No
		Brown	Text	Seg	E	No	No	No	No	No	No
Graphic display	Background	Black			NA	NA	NA	NA	NA	No	NA
	Title bar background	Cyan	Filled bar	Seg	E	Y	No	No	No	No	NA
	Title bar text	Black	Text	Default	NA	No	No	No	No	No	No
	Datablock and routes	White	Text, line	Default	NA	No	No	No	No	No	No
		red	Text, line	Att	D	No	No	No	No	No	No
				Iden	NE						
		Muted red	Text, line	Iden	NE	No	No	No	No	No	Y
		Yellow	Text, line	Iden	NE	No	No	No	No	No	No
		Muted yellow	Text, line	Iden	NE	No	No	No	No	No	No
	Airport code in datablock	Cyan	Box frame	Iden	E	No	No	Y	Y	No	No
	Spacial zone	Cyan	Line frame	Iden	E	No	No	No	Y	No	No

(Continued next page)

Table 1. URET color documentation and analysis (continued)

Plan display	Background	Black		NA	NA	NA	NA	NA	NA	No	NA
	Title bar background	Cyan	Filled bar	Seg	E	Y	No	No	Y	No	No
	Title bar text	black	Text	Default	NA	No	No	No	No	No	No
	Plan evaluation	Red	Text	Iden	E	No	No	No	No	No	Y
		Green	Text	Iden	E	No	No	No	No	No	No
Default color		White and occasionally black if the background is a bright color									
Sets of color-coding		(Red, Yellow, Brown, Cyan) for flight status (Brown, Orange) for flight ID (Cyan, Brown) for route (Brown, Yellow) for altitude (Cyan) for special flight zone (Red, Green) for plan evaluation									
Number of colors		9									
Number of color usage		16									

These symbols in Tables 1-3 represent the longer words:

dis — distraction
unc — coding uncertainty
int — loss of integration,
mul — multiple color schemes
exp — experience interference
read — text readability.
Att — attention
Iden — identification
Seg — segmentation.
Eff — effectiveness
E — equally effective
NE — not effective
NA — not applicable
D — The effectiveness of color depends on other factors
Y — yes

Table 2: TMA color documentation and analysis

Window	Component	Color	Usage	Purpose	Eff	Drawback factors					
						Dis	Unc	Int	Mul	Exp	Read
Main window	Background	Black	Filled area	NA	NA	NA	NA	NA	NA	No	NA
	Menu bar background	Cyan	Filled bar	Seg	E	No	No	No	No	No	NA
	Menu bar text	White	Text	Default	NA	No	No	No	No	No	No
Timeline	Background	Black	Filled area	NA	NA	No	No	No	No	No	NA
	Titlebar	Cyan	Filled strip	Seg	E	No	No	No	No	No	NA
	Title text	White	Text	Default	NA	No	No	No	No	No	No
	Time axis	White	Line, Text	Default	NA	No	No	No	No	No	No
	Aircraft tag	Green	Text	Iden	E	No	No	No	Y	Y	No
		Yellow	Text	Iden	E	No	No	No	Y	No	No
		Turquoise	Text	Iden	E	No	No	No	Y	No	No
	Tracking symbol	Orange	Lined symbol	Iden	E	No	No	No	Y	No	No
	Delay time	Red	Text	Iden	E	No	Y	No	Y	Y	Y
		Yellow	Text	Iden	E	No	Y	No	Y	No	No
		Orange	Text	Iden	E	No	Y	No	Y	No	No
		Green	Text	Iden	E	No	Y	No	Y	No	No
	Rush alert	Red	Heavy brackets	Att	E	No	No	No	No	No	No
Load graph	Background	Black	Filled area	NA	NA	No	No	No	No	No	No
	Axes	White	Line, Text	Default	NA	No	No	No	No	No	No
	Curves	Yellow	Curve	Iden	E	No	No	No	Y	No	No
		Green	Curve	Iden	E	No	No	No	Y	No	No
		Turquoise	Curve	Iden	E	No	No	No	Y	No	No
	Capacity indication	Red	Line	Iden	E	No	No	No	Y	Y	No
Default color		White for graphics and green for text of normal status									
Sets of color-coding		(Green, Yellow, Turquoise) for aircraft tag (Orange) for aircraft without tracking information (Red, Yellow, Orange, Green) for delay time (Yellow, Green, Turquoise) for curves of load graph									
Number of colors		7									
Number of color usage		17									

for that aircraft. In that case, TMA computes time of arrival using the filed flight plan of the aircraft, and the symbol is displayed in orange.

The delay time for every aircraft is displayed as the number of minutes along the time axis. The four colors indicate length of delay: green for 0-5 min, yellow for delays of 5-10 min, orange for delays of 11–15 min, and red for delays longer than 15 min. Thus, the four colors are used to identify lengths of delay, yet red is also used to capture users' attention. A pair of red heavy brackets on the time axis indicates a rush-time alert.

Timeline uses three sets of color-coding to identify different types of information: (green, yellow, and turquoise) for aircraft tag, (orange) for tracking symbol, and (red, orange, yellow, green) for delay time. An apparent drawback is that green, yellow, and orange are all assigned to more than one meaning. Also, red is used for both rush time alert and the longest period of delay time.

The color-coding of delay time has several drawbacks. One of these is coding uncertainty. While colors represent four distinctive categories of delay time, users need to know the exact amount of delay time. Thus, users have to make an effort to ignore the meaning of the color and acquire the information by reading the text. In addition, it is questionable whether red should be used to identify the category of delay time longer than 15 min. Lengthy delays are not as critical as a warning or alert message, although long delay times are important for users to be aware of. The last drawback is the low text readability of red on a black background.

Load graph

The load graph shows present and future traffic flows. The graph displays two curves along the horizontal time axis: Green indicates the expected traffic demand, and a yellow curve indicates the planned arrivals. In addition, a red horizontal line indicates the airport acceptance rate set in TMA. The use of red in this instance is against the convention that red should be reserved for alerts. Both green and yellow are already assigned to multiple meanings in the timeline. In real operations, users often overlay a small load graph window with the timeline window. Therefore, green and yellow would each represent three different types of information within the same view field.

General information

The default color is white for axes on the timeline and load graph. There is no default color for text; even green is associated with specific meanings. Therefore, a user has to remember and comprehend color meanings for every displayed item other than the axes, and that imposes an additional mental workload on users. As for color complexity, seven colors are used. The total number of color uses is 17. Four sets of colors are used for identification, and nearly every color is used to identify multiple types of information.

Integrated Terminal Weather System (ITWS)

ITWS is an automated weather information system that is used at terminal facilities. ITWS integrates a number of products that detect and predict such various types of weather as windshear, microburst, gust fronts, and tornadoes. The system also displays precipitation, tracks speed and direction of storm cells, and predicts the movement of storms. The display components of ITWS include product status, alert panel, graphics product, and site situation display. On the upper portion of the display are alert panel and product status buttons; the lower portion displays the graphics product. The site situation display is in a click-to-open window that is often overlaid with the graphics product. The results of the color use analysis for these components are described next and summarized in Table 3.

Product status

The product status panel consists of text buttons that show the status of the weather products in the graphic product display. Each button contains black text, indicating the product represented in this button. For example, "Precip" represents precipitation and "MB" represents microburst. The background color of a button reflects the status of the associated weather product. If a product is unavailable, the button is red. If a product is available and activated, the button is green. If a product is available but deactivated, the button is white. If the product is available and is being filtered, the button is yellow. If the product is not supported, the button is gray. Therefore, red, green, yellow, white, and gray are used to identify the status of weather products. There is no redundant cue for the product status; the text and position of a button only indicate the type of the product but not the status.

Several drawback factors exist in the product status color-coding set: 1) all four colors are used to represent other types of information in ITWS; 2) while not intended to draw attention, the white, yellow, and red buttons are so salient that they could distract a user's attention from other displayed materials; and 3) the uses of white and red are against the conventions of color use; that is, white is typically for the default or normal status, and red should be reserved for information that needs immediate attention.

Table 3: ITWS color documentation and analysis

Component		Color	Usage	Purpose	Eff	Drawback factors					
						Dis	Unc	Int	Mul	Exp	Read
Background		Gray	Filled screen	NA	NA	NA	NA	NA	NA	No	NA
Product status	Background	Gray	Filled area	Default	NA	NA	NA	NA	NA	No	NA
		Green	Filled box	Iden	E	No	No	No	Y	No	No
	Background of buttons	White	Filled box	Iden	E	Y	No	No	Y	Y	No
		Yellow	Filled box	Iden	E	Y	No	No	Y	No	No
	Button text	Red	Filled box	Iden	E	Y	No	No	Y	Y	No
		Black	Text	Default	NA	No	No	No	No	No	No
Alert buttons	Background of buttons	Gray	Filled area	Default	NA	NA	NA	NA	NA	No	NA
		Green	Filled area	Iden	NE	No	No	No	Y	No	No
				Att	D						
		Yellow	Filled area	Iden	NE	Y	No	No	Y	No	No
				Att	D						
		Purple	Filled area	Iden	NE	No	No	No	No	Y	No
				Att	NE						
		Red	Filled area	Iden	NE	Y	Y	No	Y	No	No
				Att	D						
		White	Filled area	Iden	NE	Y	No	No	Y	No	No
				Att	D						
		Black	Filled area	Iden	NE	No	Y	No	Y	Y	No
				Att	NE						
	Button text	Black	Text	Default	NA	No	No	No	No	No	No
		White	Text	Default		No	No	No	No	No	No
Graphics product	Background	Gray	Filled window	Default	NA	NA	NA	NA	NA	No	NA
	Map	Black	Line	Default	NA	NA	NA	NA	NA	No	NA
	Precipitation	Light Green	Filled area	Iden	NE	No	No	No	Y	No	NA
		Green	Filled area	Iden	NE	No	No	No	Y	Y	NA
		Yellow	Filled area	Iden	E	No	No	No	Y	No	NA
		Light orange	Filled area	Iden	NE	No	No	No	Y	No	NA
		Orange	Filled area	Iden	NE	No	No	No	No	No	NA
		Red	Filled area	Iden	NE	Y	No	No	Y	No	NA
				Att	D						
	Windshear	Red	Open circle	Iden	D	Y	No	No	Y	No	NA
				Att	NE						
	Microburst	Red	Filled circle	Iden	D	Y	No	No	Y	No	NA
				Att	NE						
	Gust front	Purple	Line	Iden	D	Y	No	No	No	No	NA
				Att	NE						
	(Continued next page)										

Table 3: ITWS color documentation and analysis (continued)

Graphics product	Tornado	Black	Filled triangle	Iden	NE	No	No	No	Y	No	NA
				Att	NE						
Site situation display	Window background	Slate blue	Filled window		NA	NA	NA	NA	NA	Y	NA
	Title bar background	Blue	Filled bar	Seg	E	No	No	No	No	No	NA
	Title text	White	Text	Default	NA	No	No	No	No	No	No
	Menu bar	Gray	Filled bar	Default	NA	No	No	No	No	No	No
	Menu text	Black	Text	Default	NA	No	No	No	No	No	No
	Table background	Gray	Filled area	Default	NA	No	No	No	No	No	No
	Table frame	White	Lines	Default	NA	No	No	No	No	No	No
	Table title	Red		Seg	E	No	No	No	Y	Y	No
	Table text	Black	Default								
	Airport code	Red	Filled box	Iden	E	No	No	No	Y	No	No
				Att	NE						
		Yellow	Filled box	Iden	E	No	No	No	Y	No	No
		Blue	Filled box	Iden	E	No	No	No	No	No	No
		Black	Filled box	Iden	E	No	No	No	Y	Y	No
Default color		Black									
Sets of color coding		(Green, White, Yellow, Red) for product status (Gray, Red) for airport indicator (Gray, White) for product automatic transition indicator (Green, Red) for TDWR status (Green, Yellow, Purple, Red, White, Black) for weather alerts (Light green, Green, Yellow, Light orange, Orange, Red) for precipitation (Red, Yellow, Blue, Black) for airport code									
Number of colors		9									
Number of color usages		24									

Alert panel

The alert panel, located in the upper-right portion of the ITWS display, consists of one or more rows of nine element boxes. Each row represents an airport. The elements (from left to right) are the airport indicator, product automatic transition indicator, status of TDWR, and six weather alert products. The default color of the airport indicator box is gray and red when a severe weather alert is detected. The product automatic transition indicator box is gray for manual transition and white for automatic transition. The TDWR status box is green if the product is available and red when it is not available. When hazardous weather is detected in a terminal area, the boxes of the six alert products light up. An alert box is gray when the product is not available or no alert is detected. When an alert is detected, the corresponding box lights up with a specific color. The colors are red for microburst, white for windshear, purple for gust front impacting within 20 min, yellow for lightning within 20 miles, and black for tornado and anomalous propagation. By lighting these boxes with colors, the display draws a user's attention to the situations that may be potentially dangerous or may require a change in the runway configuration or airspace. Therefore, the colors are used mainly for attention. The colors also help users to identify types of weather, with location and text being the redundant cues. The default text color is black for most of the boxes and white for the purple and black boxes to enhance readability. An exception is that the text is red to draw attention to the white box when a windshear alert is detected.

Seven colors are used in the alert panel. Each color identifies one or several types of information. However, the colors appear to have limited effectiveness. Visual experiments have demonstrated that the advantages of color in identification tasks disappeared when the number of colors reached 6~7 (Carter, 1982). The lighted colors are also used to draw attention. Among them, black and purple are not effective for attention because of their low luminance. Additionally, while red, white, and yellow are salient enough to draw attention out of the boxes in gray (the normal status), the effectiveness is dependent upon no other boxes being lit. A user cannot effectively attend to a salient target when more than two other targets are also salient in the field of view (Julesz, 1965). In addition, the red text for detected windshear is not salient enough to effectively draw attention because it is displayed in a white-filled text box.

Color use in the alert panel has several drawbacks. First, there is uncertainty in the red and black categories. Red has multiple meanings in the panel; therefore, a user must use additional cues such as the text or button location to infer the meaning of red. The same is true for black, as it may mean either a tornado or an anomalous propagation. Second, most of the colors (green, red, white, yellow, and black) are used in other parts of ITWS for other purposes. Third, the use of black and purple for attention is against the conventions of color use.

Graphics product

This product displays weather precipitation in filled areas. Intensity values of precipitation are based on National Weather Service intensity levels. Six colors (light green, green, yellow, light orange, orange, and red) represent level-1 to level-6 precipitation. The graphics product also displays severe weather including microbursts, windshear, gust fronts, and tornado alerts. Each of these weather types is indicated with a specific color and a shape (as the redundant cue) and is overlaid with areas of precipitation. Gust fronts are displayed as solid purple lines corresponding to the location of detected gust fronts, as well as dashed purple lines indicating the predicted position of the gust front in 10 and 20 min. Detected windshears are presented as open red circles with the corresponding strength indicated inside the circle. Microbursts are presented as solid red circles with the strength indicated inside the circle. Detected tornatoes are presented as solid black triangles inside an open black circle.

While six colors are used to identify precipitation levels, the chromaticity difference between light green and green is too small for users to reliably identify level 1 from level 2 precipitation. When these two colors are used for identification together with many other colors, users tend to merge the two colors into one "green" category. The same is true for orange and light orange. Thus, these four colors, green, light green, orange, and light orange, cannot effectively identify the four assigned weather levels. Red represents the highest level of precipitation; thus, it is used for both identification and attention. Its effectiveness in attention depends on the size of the filled area. When the area is relatively large, it can potentially distract the perception of other severe weather alerts, and the detectability of those alerts is consequently reduced.

Three colors, red, purple, and black, are used for severe weather alerts that overlay filled precipitation areas. These colors are used for both attention and identification. As stated earlier, purple and black are not effective for attention. The effectiveness of red in attention depends on the size of the microburst or windshear circles. The effectiveness in identification depends on how many colors of precipitation exist in the view field.

Site Situation Display

The Site Situation Display presents a table of weather situations for a number of terminal areas. Each row represents an airport. The background of the window is slate blue, and the background of the table is gray. The elements in the table (from left to right) are: airport code, mode, alert, and storm information. The title texts of elements are red. The text background of airport codes is color-coded to represent the operational status of weather sensors: yellow for storm cells, red for action alert, blue for operational, and black for not-operational. The text of airport codes is black for the yellow background and white for red, blue, and black backgrounds.

Among the four colors that identify the weather status of an airport, red and black have multiple meanings in other components of the ITWS display. Red is also used to draw attention to action alerts. However, it is not effective for attention due to its low luminance. In addition, red is used to segment element titles. This color usage is against the convention that red should be reserved for alert or warning messages.

General information

The background color is gray in most components of the display; however, it is slate blue in the site situation display. The default color is black. A total of nine colors are used in ITWS. However, the number of color uses is 24. Seven sets of color-coding are used to identify categories of information. One of the major problems with the color-coding of ITWS is that most colors are used to represent more than one type of information. Another problem is that too many colors are used for the purpose of attention. Since the attention capacity is limited, the effectiveness of each color in drawing attention is greatly reduced when several salient colors are used simultaneously.

Effectiveness and drawbacks of color use in the three displays

We calculated the total number of instances in which color use is not effective for its given purpose, or the effectiveness depends on other attributes. That is the number of times "NE" and "D" appear in the "Eff" column in each of the summary tables. We also calculated the number of drawback factors for each display. That is the number of times "Y" occurs in the six right-most columns in each table. These two numbers together can reflect the overall effect of color use in a display. Figure 1 shows the results. The upper and lower panels indicate effectiveness and drawbacks, respectively. From left to right along the horizontal axis are the three decision-support displays: URET, TMA, and ITWS. The vertical axis of the upper panel represents the number of "NE" and "D;" the vertical axis of the lower panel represents the number of "Y" in drawback factors. Figure 1 indicates that both URET and ITWS have instances where the use of color is not effective. Moreover, all of the displays have a number of color usages that may negatively affect task performance. ITWS has an extremely high number of "NE" and "D." That is partly because ITWS uses too many colors to draw attention or to label categories of information. When too many colors compete for attention, typically, none of them gets attention. Similarly, having too many color categories is equivalent to having no category.

Color complexity in the three displays

Three indices were used to measure color complexity: the number of colors, the number of color uses, and the number of sets of color-coding. For any given task purpose, the effectiveness of color decreases with the increase of these indices (Xing & Schroeder, 2006). Figure 2 shows the three indices for each of the three displays. The top, middle, and bottom panels correspond to the numbers of colors, color usages, and sets of color-coding, respectively. In each panel, the vertical axis represents the corresponding index. The three displays are listed along the horizontal axis from left to right (URET, TMA, and ITWS). The dashed horizontal line in the top and bottom panels each represents a saturation number beyond which the effectiveness of color begins to decrease, if not completely diminish. The saturation number of colors is six and the number for sets of color-coding is three, inferred from the literature (Carter, 1982; Cummings,

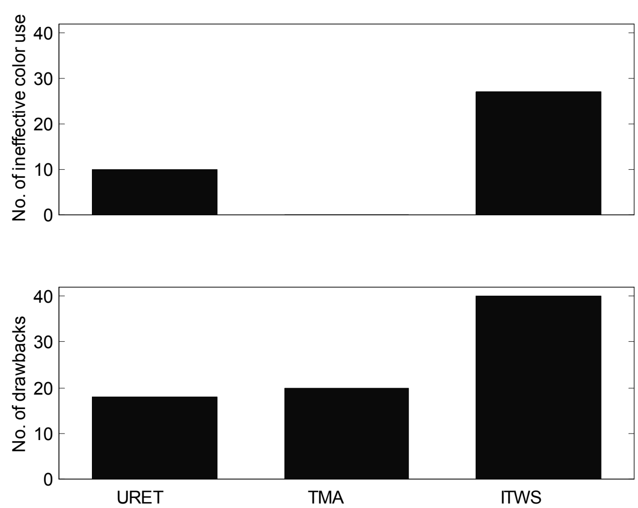

Figure 1: Effectiveness and drawbacks of color use in three ATC displays (URET, TMA, and ITWS).The vertical axis of the upper panel represents the number of ineffective color use, and the lower panel represents the number of color use that negatively affects ATC task performance.

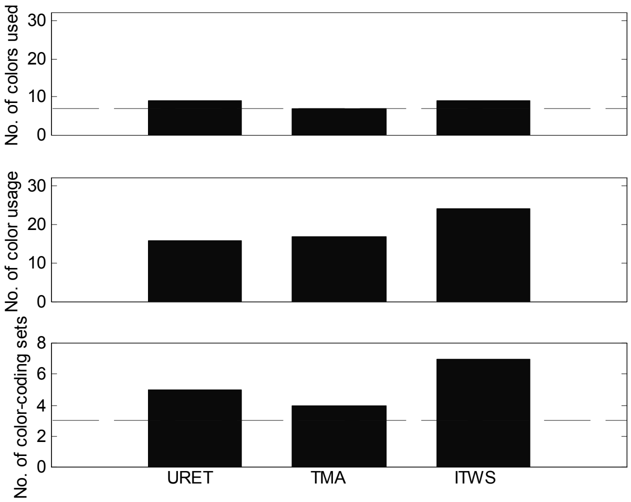

Figure 2: Color complexity in three ATC displays (URET, TMA, and ITWS). The top, middle, and bottom panels correspond to the numbers of colors, color usages, and sets of color-coding, respectively. In each panel, the vertical axis represents the frequency index.

Tsonis, & Xing, 2006; Yuditsky et al., 2002). Information about the saturation number for color uses is not available in the current literature.

Figure 2 indicates that both URET and ITWS use more than six colors, while TMA is on the saturation point. The positive difference between the number of color uses and the number of colors for a given display indicates that some colors are used to represent more than one type of information. Therefore, a color is not completely correlated with a given meaning. Such coding is not efficient in conveying information. All three displays have some degree of such uncorrelated coding. In the bottom panel, each display uses color sets beyond the saturation line, especially the ITWS, suggesting that the effect of color is not optimal. Overall, the three auxiliary displays have greater color complexity than the radar displays (Xing, 2006), suggesting a general lack of human factors considerations in the development and evaluation of decision-support tools.

Color consistency across displays

As mentioned in the introduction, since a controller typically uses several displays, it is important to make the color-coding consistent across displays. Once we documented the color-coding for each display, it was easy to check the color consistency, given that the same format was used to document color use in each display. We utilized the following procedure to check color consistency across displays:

1) Identify the display-wide color information: background colors, default text / graphic colors, and alert/emergency colors;
2) Identify the meanings of each color that is co-used in the related displays; and
3) Identify the colors of each displayed element that co-exist in the related displays.

To demonstrate how to use this procedure, we applied the procedure to assess the color consistency between URET and DSR (URET is intended to be used along with DSR). The results are shown in Table 4. The rows of the table represent the items to be checked, and the columns are the displays and the consistency. Each cell in the table is filled with the information presented in the color documentation tables of the displays.

Display-wide color use

The background color is dark blue/black for DSR and gray for URET (inconsistent). However, since controllers can adjust the background color of DSR, it is difficult to make the background color of URET consistent with that of DSR.

The default color for presenting information in the normal status is green for DSR and white for URET (inconsistent).

The color used for alert/emergency information that requires immediate attention is red on both DSR and URET, so this color is used consistently across the displays.

Meaning of common colors

Three colors are used in both DSR and URET: red, green, and brown. Red is used for conflict alert in both displays; green is used as the default color in DSR, but it represents non-conflict flight plans evaluated by URET, so it is not consistently used; brown is used to indicate the current flight altitude in DSR, yet it is used to identify aircraft that do not have tracking data in URET; so the meanings are inconsistent.

Colors of common elements

The only common element displayed in both DSR and URET is the conflict alert. The same color red is used for this purpose.

It is desirable that all the cells in the "Consistency" column are filled with "Yes." However, that is not the case for most displays. When a cell is marked as "No," the developers should assess the operational effects of the inconsistency. If there is a high probability that the inconsistency may lead to misinterpreting critical information, then the color-coding needs to be modified. In other instances, the inconsistency may lead to mild consequences such as increasing visual fatigue and controllers' unwillingness to use an auxiliary display.

Table 4: Assessment of color consistency between DSR and URET

Items to be checked		DSR	URET	Consistency
Display-wide color use	Background color	Dark blue / black	Gray	No
	Default color	Green	White	No
	Alert/Emergency	Red	Red	Yes
Meaning of common color	Red	Conflict alert	Conflict alert	Yes
	Green	Default color	Non-conflict plans evaluated	No
	Brown	Current altitude in flying-out window	Listed aircraft with no tracking data	No
Color of comment element	Conflict alert	Red	Red	Yes

Notice that we did not take the graphic tool of DSR into the consideration of color consistency. The reason is that the controller may choose one of the four colors to indicate a special flight region in the airspace. Theoretically, a controller can always choose a color that does not cause inconsistency with other color uses in the displays.

DISCUSSION AND CONCLUSIONS

This report presents the results of a color analysis of three auxiliary ATC displays. The results allowed us to compare the use of color and to examine color consistency in a controller's workstation that may consist of several displays. For instance, an en route controller may use both DSR and URET. By comparing their color-documentation tables, we can quickly ascertain several key differences between the two displays. For example, the two displays use different default colors; the DSR default color is green while URET uses both white and black for default text.

An immediate effect of inconsistency in background or default colors is the increase of visual workload for users. The visual system devotes more activities to responding to differences in visual inputs than to the absolute value of the inputs. Therefore, the brain responds strongly to the onset and switch of colors but only weakly to the static presence of color. Since the background and default colors represent a majority of the visual stimuli in a display, switches between colors generally trigger brain activity, which can increase visual fatigue, reduce brain resources devoted to important information, and lead to a higher probability of missing critical messages that onset simultaneously with the switches. To better understand these consequences, imagine the situation where each paragraph of this report was printed with a different text or background color.

Inconsistency in color-coding can also lead to missing or misinterpreting color-coded messages. Inconsistent color-coding increases information uncertainty; thus, the brain's representation of the meaning of a color can be biased (Green & Swets, 1988). Such biased responses can affect controllers' decision-making. For example, red in a primary display is used for alert and warning. If some supporting displays use red frequently for non-critical information, the alert level of the brain's response to red would be reduced. When a controller shifts his attention from an auxiliary display to the operational display, a red alert message may not trigger significant alert responses in the brain. Thus, color-coding for mission-critical messages should be consistent across displays.

The ideal way of assuring color consistency in and across displays is to ensure that one color has a single distinct meaning. However, this is difficult to achieve in reality because of the complexity of ATC displays. Sometimes it is necessary to use one color for different meanings. When consistency cannot be achieved, a compromise solution would involve compatibility. That is, if a color is used for multiple meanings, the meanings should not conflict. For example, if red is used for multiple meanings, each should be to gain attention or alert. The same principle applies to other aspects of the integration of new technologies (Cardosi, 2003).

In summary, this report provides an example of evaluating and documenting the use of color in ATC displays. The results also reveal a general lack of human factors considerations in terms of color use in the design and evaluation of ATC technologies. We encourage ATC technology developers and interface designers in ATC facilities to perform similar evaluation and documentation, as we did in this study, to improve the usefulness and effectiveness of their technologies.

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