Why Gray Backgrounds for DCS Operating Displays? The Human Factors Rationale for an ASM Consortium Recommended Practice

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In the control room environment, operating displays serve an important role in supporting operator situation awareness and executing actions to prevent and respond to abnormal plant situations. Operator situation awareness involves orienting to the presence and location of a disturbance, comprehending the nature of the underlying plant conditions, and projecting the impact of the disturbance into the immediate future to determine the appropriate course of action. The operator display design directly impacts the speed and accuracy of an operator performing these abnormal situation management activities.

The recent evolution of distributed control systems (DCS) to PC-based computer platforms has been accompanied by a significant change in capabilities to present data and information to operators. In particular, the ability to render those first-generation color schematic displays has evolved from the limited use of eight colors with full and half intensity to potentially millions of colors with the ability to manipulate combinations of saturation, hue and intensity levels.

The early DCS schematic displays were implemented with these limited color options on black background screens. Moreover, because of the limited colors available, the same color was often used to visually code different data types or status information. For example, the color red might be used to communicate a valve is closed, a pump is stopped, a process parameter is in alarm, and a process line is transferring oxygen.

In parallel to the shift in DCS display technology, the use of black background on CRT screens created an unexpected impact on control room lighting. This unexpected result was in part due to the curvature of the CRT screen itself and in part the phenomena of creating a' mirror' out of the CRT glass with the extreme contrasts of 'light' on each side of that glass. The result was excessive glare and the response in almost all control rooms was a migration from bright, well lit control rooms (with pneumatic control panels) to dark, dimly lit control rooms with multiple CRT based console workstations.

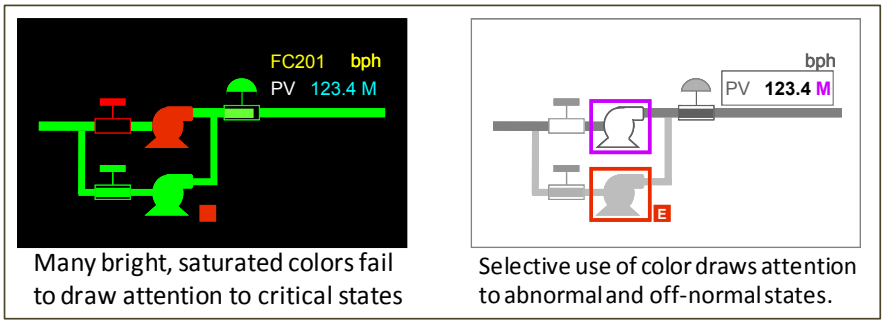
In the mid-90s, the Abnormal Situation Management® (ASM®) Consortium began studying factors that impacted the ability of operators to prevent and respond to abnormal situations in the plant. One of the conclusions at the time was that the present day technology supports operators more effectively during steady-state operations than during upset operations. Operator schematic display design was one factor that was identified as needing improvement to support effective operator situation awareness and performance. Consequently, the ASM Consortium began researching human factors in operator display design to identify effective practices based on plant implementations as well as human factors research in academia and other industries.

This research resulted in the ASM Guidelines publication of the *Effective Operator Display Design* and one of the sixteen guideline areas was on the effective use of color in operator displays [1]. Within this guideline area there are eight guidelines on the use of color; one of which is the choice of color for display backgrounds. The color-specific ASM guidelines are intended to aid the display designer in selecting a color scheme that enhances the overall operator performance in the control room environment, not how to design an 'attractive' display. The color scheme guidelines were created with the understanding that this work context places specific demands on the operator that are not present in contexts such as an office, public facility or home. For example, operators must maintain continuous alertness over long shifts and monitor for infrequent events that may occur at unknown times. In this context, it is vital the display captures the operator's attention—particularly when the vigilance performance decrement has been demonstrated across multiple industries for monotonous, low frequency events—when critical data is changing.

Subsequently, the recommended design practice of using light gray backgrounds on DCS operating displays emerged as a result of several interacting design objectives. A few of these design objectives are

- directing the operator's attention to the most critical information with the least possibility for confusion, slow response, or errors in detection or interpretation
- addressing concerns with respect to individuals that might have color vision deficiencies
- reducing glare so ambient light levels are high enough to support both visual acuity for non-display tasks (e.g., reading paper copy) and also biological clock adjustments for the appropriate day or night shift

To understand the factors that influence design decisions on use of color in operator displays, it is important to understand some basic principles of human sensation and perception. To enhance situation awareness, visual coding techniques are used to draw the operator's attention to the most critical data and information through enhancing the salience of the associated display elements. An object is more salient than another object if it 'stands out' or grabs one's attention. In terms of the display design then, this object appears to be in the foreground of the display relative to other objects. The visual attributes that the designer can manipulate to create different degrees of salience include movement, form and color. Luminance and color contrast depend on the brightness and color attributes to define the visual distinctiveness of a symbol or object from its immediate background. A minimum level of luminance contrast is necessary for legibility. Manipulating degrees of luminance contrast is effective for managing the viewer's attention. The most safety-critical or urgent information should stand out the most in the display foreground whereas less important, static data or information that provides context, such as vessels or display background, should blend more to the background. For operator situation awareness, it's important to emphasize abnormal states, off-normal conditions and dynamic data. If the designer is using color to manipulate salience, it is important that the color is used discriminately to code a specific meaning, that is, if red means critical alarm state then it should not also mean a pump is off (which might be normal state). Non-discriminant coding requires the viewer to use additional mental effort and time to exhaustively scan similar colored objects in an operating display and evaluate what the red means in each instantiation on display objects.



To maximize the ability to manipulate salience, the designer needs to consider how the background color supports both effective luminance and color contrast. From a luminance contrast perspective, the designer could choose white, black or gray background. A white or black background will provide maximum luminance contrast with dark or light text or objects. Research has shown that the ability to see detail (i.e., visual acuity) is better for dark text on white backgrounds [2]. From a color contrast perspective, the use of a light gray scale background enables the use of a broader range of *foreground* color choices for manipulating salience than a light colored background such a tan, green or blue, particularly when one considers the impact on individual's with color vision deficiencies. With a non-gray colored background, certain regions of the foreground color palette fall into the same color spectrum as the background color, reducing the color contrast for normal color-vision individuals and increasing the likelihood of confusion or mistakes for individuals with color vision deficiencies.

So why not use a white background display instead of gray? One reason is that the background display color in combination with the ambient light level of the control room can impact the probability of eye strain and fatigue as well as visual acuity. When someone is looking at a bright display in a dark room or a dark display in a bright room,

the eye has to make an adaption to the change in luminance as their eyes move about the room and at the displays With the successive viewing of light and dark sources over the period of a 12 hour shift, operators may experience eye strain and fatigue [3].

From the operator perspective, the background luminance of their displays will be the main determinant of their eye adaptation level [2]. Hence, keeping the contrast between ambient lighting in the control room and background display luminance to a minimum can improve eye comfort. In addition, visual acuity has been demonstrated to be better when the surround or ambient luminance is equal to the display luminance. Hence, the recommendation of a light display background is coupled to the recommendation for high ambient lighting in the control room.

A key consideration for deciding on ambient control room light levels is its impact on operator alertness. Low alertness levels are shown to reduce operator performance. The long work shifts (typically 12 hours) coupled with a rotating shift schedule presents significant challenges to operators in maintaining an effective alertness level due to the impact on their biological clock. Working in a dark control room exacerbates the challenge of maintaining alertness because it causes a physiological reaction that facilitates sleeping. Hence, bright, well-lit control rooms can improve operator alertness levels and subsequent performance.

In conclusion, the combination of design factors that impact operator situation awareness, alertness, eye strain and fatigue led to the general recommendation to use a light colored background on operating displays in a well lit control room. Secondly, for a broader choice of colors that provides an effective contrast against the display background color, most operator display designers end up choosing gray as the back ground color as opposed to tan, green or blue. In the end, the ASM Consortium recommends grey backgrounds due to the positive impact on operator performance rather than on operator preference for aesthetically pleasing colored displays. Moreover, the ASM Consortium does NOT recommend only using grayscale in display design but to use an effective color scheme to establish the relative importance of information and subsequently communicate distinctive meaning at a glance. However, display designers must realize that color usage is only one of several considerations when designing an effective operator display. The ASM Consortium guidelines provide a comprehensive set of recommendations for ensuring the operator display maximizes human performance when dealing with abnormal situations.

[1] Bullemer, P.T., Reising, D.C., Burns, C., Hajdukiewicz, J., and Andrzejewski, J. (2008). *Effective operator display design*. ASM Consortium Guidelines Book. Minneapolis, MN: ASM Consortium.

[2] Arend, L., Logan, A., and Havin, G. (2011) *Using color in information displays graphics*. NASA Ames Research Center, http://colorusage.arc.nasa.gov.

[3] Panel on Impact of Video Viewing on Vision of Workers. (1983). *Video Displays, Work, and Vision.* Washington, DC: National Academic Press.