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BNSF Energy Management
Human Factors Evaluation
Separate Screen Configuration

Final Report

April 14, 2016

Enclosed Document Revision Histories

Heuristic Evaluation & Cognitive Walkthrough

REV	DATE	AUTHOR	NATURE OF REVISION
0	1/20/2016	C. Johnson	Draft release.
1	2/16/2016	C. Johnson	Updates based in meetings with BNSF and GE Transportation
2	4/14/2016	C. Johnson	Resolution of issue: • "Rolling Map" button renamed to "Start TO PTC Trip", • Removed obsolete sentence regarding the "Welcome Screen".

Cognitive Workload Assessment of Crew Interactions with EM

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1	3/4/2016	C. Johnson	Correction of issues: • system enters Forced Idle if operator does not respond to prompts related to shifting to Auto Control.
2	4/14/2016	C. Johnson	Additional information provided: • End trip key is available while train is moving to allow operator to exit TO in the event of a system failure

Analysis of Appendix E of 49 CFR Part 236 Subpart I

REV	DATE	AUTHOR	NATURE OF REVISION
0	01/20/2016	C. Johnson	Draft release.
1	2/16/2016	C. Johnson	Updated based on meetings with BNSF and GE Transportation.
2	3/4/2016	C. Johnson	Correction of issues: • system enters Forced Idle if operator does not respond to prompts related to shifting to Auto Control.
3	4/14/2016	C.Johnson	Minor typos resolved.

Ergonomic Analysis of AAR Screen & CDU Placement

REV	DATE	AUTHOR	NATURE OF REVISION
0	03/15/2016	C. Johnson	Initial release.

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1 Introduction

BNSF Railway is implementing Energy Management (EM) features into their existing locomotives. There are two alternative implementations of the EM features:1) integrated into the existing Association of American Railroads (AAR) onboard display; 2) integrated in the Positive Train Control (PTC) onboard display. The two implementations will not be used simultaneously on the railroad; the implementations may be staged as separate phases, or the railway may choose to move forward with only one implementation. As such, the implementations have been evaluated separately, as consistency between implementations is less important than consistency of each implementation with the user interface of the onboard display in which the implementation will be integrated.

This evaluation examines the implementation that will integrated the EM features into the AAR onboard display.

1.1 Purpose and Description of EM

The primary purpose of EM is to allow the crew to optimize resources during the course of a train trip. This is done by allowing EM to control speed via the throttle and dynamic braking while in Auto Control Mode and by providing a graphical indicator of the plan speed while in Manual Control Mode.

In this implementation of EM, the UI consists of information displays and interaction components that are integrated into the existing AAR screen designed by GE Transportation. These include depictions of upcoming and preceding track (5 and 2 miles, respectively); speed and control related indications; visual prompts and messages to the operator; audible tones; and push-button controls.

In this implementation, EM may be run in combination with PTC, with is controlled and presented through a separate screen (the CDU), or may be run in a standalone mode without PTC enforcement. The differences between these modes re as follows:

- Without PTC the engineer must verify information such as the Train Setup and Restrictions. With PTC this information will have already been verified as part of the PTC initialization process.
- Without PTC the engineer must bring the train to and keep it at zero speed to start a Trip Optimizer trip (this is due to the need to verify that additional information). With PTC the TO trip can be started at non-zero speeds.
- With PTC, TO will re-plan the trip with signal aspect changes. Without PTC, TO assumes that are signal aspects are green.
- The button to start a trip is "New Trip" without PTC and "Start TO PTC Trip" with PTC.

1.2 Onboard Display Hardware

The AAR onboard display consists of a color screen display with push-button controls arranged in 2 horizontal rows directly below the screen. Additional buttons along the side of the unit allow the operator to control brightness and contrast for the LCD screen, but are not used for data input.

This hardware is already in use for other locomotive functions, and is therefore "proven in use". As such, no separate functional evaluation is required regarding the screen's readability under all typical locomotive lighting conditions for the upper and lower limits of brightness and contrast, viewing and spatial characteristics, luminance and color quality, required button force and displacement, or the audibility of the alert and alarm tones (decibels and frequencies) in consideration of the ambient noise level typical of locomotives.

1.3 Overview of Crew Interactions with EM

EM is intended to enhance the crew's use of resources during the course of a train run and does so by controlling the throttle and dynamic brakes while in Auto Control, and by providing implicit speed recommendations while in Manual Control.

The EM feature primarily displays information to the crew, though direct interaction with the system on the part of the engineer is required to perform the following functions, as needed:

- To initiate and end Trip Optimizer (the EM feature),
- To initiate and disengage Auto Control.

Indirect interaction with the system occurs when prompted by the system as follow:

- Adjust throttle and speed to match plan speed while in Manual Control (optional),
- Adjust throttle to enter / exit Auto Control,
- To modify air brakes when prompted by EM (EM has no connection to the air brakes).

1.4 Acronyms and Abbreviations

TABLE 1 – ACRONYMS AND ABBREVIATIONS

Term	Definition
AAR	Association of American Railroads
CDU	Central / Computer Display Unit
EM	Energy Management
HF/HFE/HFA	Human Factors / Human Factors Evaluation / Human Factors Analysis
HMI	Human Machine Interaction / Human Machine Interface
PTC	Positive Train Control
TO	Trip Optimizer

2 Assessment and Analyses Conducted

2.1 Heuristic Evaluation & Cognitive Walk Through

The goal of the first phase of the project was to analyze user interactions with this implementation of the EM features, to identify those that that are confusing or unnecessarily complex, and to provide recommendations to improve those interactions to increase operator comprehension of EM presented information and to minimize operator workload, particularly with regards to those interactions that may affect the safety of trains, equipment, and people.

2.2 Cognitive Workload Assessment of Crew Interactions with EM

A Cognitive Workload Assessment was undertaken as part of the HFA to determine whether interactions with EM will affect the cognitive workload required on the part of the train crew to safely operate the train. This evaluation focused on scenarios of operations that will occur during the course of the train journey.

2.3 Analysis of Appendix E to Part 236

This section of this report includes the analysis of Appendix E to Part 236.

2.4 Ergonomic Analysis of AAR Screen & CDU Placement

The user interface of EM is displayed on the AAR display located within the confines of the locomotive. An analysis was undertaken to examine the placement of the AAR display within the locomotive in relation to the working position of the engineer and conductor, where applicable. Note that this section of the report combines the analyses of both the AAR display and the CDU.

2.5 Human Factors Evaluator

Daedalus Human Factors and Research Manager, Carolynn R. Johnson, performed these analyses. Dr. Johnson holds a Ph.D. in Cognitive Psychology from Purdue University, with an emphasis in Human Information Processing, and has 15+ years experience in designing user interactions, conducting user research, and performing expert evaluations. Prior to joining Daedalus, Dr. Johnson led the Human Factors initiative at Ansaldo STS USA (formerly Union Switch & Signal) from 11/2005 – 12/2010, and has conducted several HFAs for Train Control systems in accordance with Appendix E of 49 CFR Part 236.

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3 Heuristic Evaluation & Cognitive Walkthrough

The goal of this phase of the project was to analyze user interactions with EM, to identify those that that are confusing or unnecessarily complex, and to provide recommendations to improve those interactions to increase operator comprehension of EM presented information and to minimize operator workload, particularly with regards to those interactions that could affect the safety of the train and railroad employees.

3.1 Methods of Evaluation

The methods and procedures of this analysis include a heuristic evaluation and cognitive walkthrough of the EM interface, including the Main Screen components and all supporting screens. A *heuristic evaluation* compares the to-be-evaluated interface against a set of industry accepted standards. A *cognitive walkthrough* involves evaluators with expertise in human factors completing the tasks the operators of the system are intended to complete and evaluating the interface in terms of its understandability, ease of use, and ease of learning.

Both methods are described in greater detail below. The purpose of both is to determine the extent to which the EM interface follows accepted human factors design practices, to identify and correct potential performance issues arising from use of the system – including errors of commission and errors of omission – and to enhance operator comprehension of presented data.

The issues discussed in this document are based on observations drawn from:

- a review of the following documents:
    - TO-PTC on GE Locomotive Display Overview R1 (pdf)
- discussions with Stephen Muncy, Director Operating Practices-Fuel Conservation/PTC, BNSF
- onsite observations noted of a demonstration engineering test system at the GE Transportation facility in Erie, PA, February 11, 2016

3.1.1 Heuristic Evaluation

A *heuristic evaluation* involves comparing the interface in question against a set of industry accepted standards. In this evaluation, reference standards consisted of relevant sections of the *ANSI/HFS 200-2006 Human Factors Engineering of Software User Interfaces.* In particular, this analysis addressed "Part 3: Interaction Techniques" and "Part 5: Visual Presentation and Use of Color" of ANSI/ HFS 200-2006.[1]

The *ANSI/HFS 200-2006 Human Factors Engineering of Software User Interface* standards were chosen for use as they represent the most comprehensive standards available within the Human Factors industry for the design of human-computer interfaces. They are more comprehensive than the *Manual of Standards and Recommended Practices, Section M, Locomotives and Locomotive Interchange Equipment* from the Association of American Railroads, particularly with regards to the design of visual displays (*8.0 General Guidelines for the Design of Visual Displays*). Likewise, *ANSI/HFS 200-2006* is more comprehensive than the *Advanced Train Control Systems*

[1] "Part 2: Accessibility" of *ANSI/HFS 200-2006* is irrelevant to this system; it addresses customization of system attributes to improve usability for users with reduced abilities. As a closed system in which multiple individuals interact with the same workstation, customization is counterproductive – users must be able to immediately interact with every locomotive workstation with a zero adjustment period. "Part 4: Interactive Voice Response & Telephony" is also irrelevant to this interface, as all interactions, with the exception of auditory alerts and alarms, are conducted via a visual interface. Note that Part 1 is an introduction to the standard.

Specification 320 Locomotive Displays and Controls (1990) and the *Human Factors Guidelines for Locomotive Cabs* (1998), also with regards to the design of visual displays.

3.1.2 **Cognitive Walkthrough**

A *cognitive walkthrough* involves evaluators with expertise in human factors completing the same set of tasks that operators of the system are expected to complete and evaluating the interface in terms of its understandability, ease of use, and ease of learning.

Evaluators must have an understanding of the users of the system, the tasks that must be completed, and the correct sequence of actions for said tasks. The procedure consists of "walking through" tasks in the same manner as expected by the operator and answering the following:

- *Will the user know what course of action is needed to achieve the desired result?*
- *Will the user see that the correct action or option is available?*
- *Will the user be able to associate the correct course of action with the desired result?*
- *Will the user understand whether a correct or incorrect course of action has been taken?*

3.2 **Limitations of Review**

This review was undertaken for the Energy Management features that are integrated into the existing AAR screen as designed by GE Transportation. This document represents a review of only the EM components, as the scope of this project does not include a review of the larger HMI.

3.3 **Prioritization of Usability Concern**

This document delineates human factors issues detected by the evaluator regarding interactions with the system on the part of the train crew. These issues are categorized as described below.

Catastrophic Issues: Usability issues that have the potential to compromise the safety of the train, crew, passengers, other railroad employees or civilians, or other equipment.

Major Issues: Usability issues that may severely impact the efficiency of train operations due to frequent or repeated but unnecessary enforcement (penalty brake applications, or in the case of EM, forced idle states), without impacting the safety of the train, equipment, or people.

Moderate Concerns: Usability issues that may contribute to confusion or stress on the part of the crew, to delayed awareness of train information, or to disrupted situation awareness without impacting safety or causing avoidable enforcement.

Minor Concerns: Usability issues that may increase processing time and user frustration or decrease operator use of and confidence in the system.

4 **Human Factors Concerns**

There are no catastrophic or major human factors concerns associated with the EM components that are integrated into the AAR screen - there are no issues that should compromise the safety of the train, personnel, or equipment, nor are there any that will likely lead to excessive but avoidable forced idle conditions.

4.1 Moderate Human Factors Concerns

There are several usability issues that may contribute to confusion or stress on the part of the crew, to delayed awareness of train information, or to disrupted situation awareness. These issues do not impact safety and are unlikely to lead to avoidable forced idle conditions. However, correcting these issues will reduce cognitive workload and potential confusion on the part of the user and will minimize disruptions to the crews' ability to maintain situation awareness.

4.1.1 Low Saliency of Control Mode

This issue has been reclassified as a minor issue. See section 4.2 Minor Human Factors Concerns.

4.1.2 Message Foreground / Background Combinations

There are 8 combinations of foreground/background color used in the Brake and Main SVP message area, 1 of which signifies critical system error, 2 of which appear to indicate that user action is required, and 5 of which provide information only.

TABLE 2 – SVP MESSAGE COLORS

Braking Messages
TARGET YYY ER
MIN SET
Min Set Ahead (xx)
MIN SET NEEDED NOW (XX)
TARGET YYY ER (xx)
TARGET YYY ER (xx)
RELEASE AHEAD (xx)
RELEASE NOW! (xx)
BAIL OFF NEEDED! (xx)
AIR ADVISEMENT NOT AVAILABLE
LOW DYN BRAKING DETECTED

Other Messages
AUTO CONTROL ACTIVE
MANUAL CONTROL ONLY
FORM B AHEAD
CALCULATING TRIP
AUTO CONTROL AVAILABLE
MANUAL CONTROL AHEAD...(##)
CURRENT TRACK UNKNOWN
FORM A AHEAD
AUTO ACTIVE CALCULATING...
UNKNOWN SWITCH AHEAD
TRANSITIONING TO MANUAL
EXITING TRIP OPTIMIZER....
MANUAL CONTROL NEEDED NOW! (##)
WAITING FOR N8 (##)
WAITING FOR MATCH... (##)
WAITING FOR CONFIRMATION (##)
TIMED OUT! GOING TO IDLE...
TIMED OUT! CONTROL IN IDLE
TRIP OPTIMIZER ERROR!

4.1.2.1 System Error Message

In standalone systems, using red to signify a system error is appropriate, as it signifies an error of the highest order and aligns with cultural conventions of red signaling bad, erroneous, or dangerous conditions, a required stop, or an error.

However, EM is not a standalone system; it is presented within the overall AAR screen, and beyond that, it is one of several displays within the locomotive. The most significant error of the EM system will not lead to dangerous conditions for the train, equipment, and personnel; nor will it lead to a penalty brake application.

As such, **WHITE on RED** overemphasizes the severity of the error condition.

It is this reviewer's recommendation that a system error that results in the inability to use trip optimizer be presented in a manner that conveys less severity.

Consider **RED on BLACK** **or** **BLACK on YELLOW**, if either of these options is available for use.

4.1.2.2 Action Required Messages

Color coding of action-required messages in this interface is appropriate. The point of color coding is to provide users with an *immediately apparent categorization mechanism*, so that users know at a glance either the group to which an item belongs or the level of severity or urgency or importance assigned to an item.

The use of **GREEN on BLACK** and **YELLOW on BLACK** to convey that an action is required is appropriate and clearly categorizes the urgency of the action, green for less urgent actions; yellow for more urgent actions, which also aligns with cultural expectations.

However, the use of **GRAY on BLACK** as an informational message (e.g. WAITING FOR PTC and TRIP OPTIMIZER AVAIABLE) reduces the clarity of the action messages above. Users may draw the incorrect conclusion that all messages with a black background require an action, and may expend cognitive effort and time attempting to determine what action is required for these messages.

Limiting black backgrounds to action messages will allow the user to understand at a glance whether or not an action is required. In other words, remove GRAY on BLACK as an informational message color combination.

Note the use of GRAY on BLACK for MIN SET and TARGET YYY ER is acceptable, as these messages are presented immediately after the action corresponding action oriented messages, indicating that the user has completed the required action and met the system requirements. However, no other informational messages should use this combination.

4.1.2.3 Informational Messages

With regards to informational messages, to this reviewer, there does not appear to be a clearly consistent reason for why a particular message is assigned to one of the 5 color combinations: **WHITE on BLUE**, **GRAY on BLACK**, **BLACK on GRAY**, **WHITE on GRAY**, or **BLACK on WHITE.**

As noted above, the point of color coding is to provide users with an *immediately apparent categorization mechanism*, so that users know at a glance either the group to which an item belongs or the level of severity or urgency or importance assigned to that item. There is no apparent urgency, severity, importance assigned to these information messages given that 4 of the 5 codes utilize only neutral colors. Therefore, this reviewer assumes that the use of color is an attempt to instead assign each message to a group. However, these presumed groups are not apparent to this reviewer, and it is highly likely that users will also be unaware of the reason for the color coding, which is directly contrary to section f10 of the regulations, "... add color only if it will help the user in performing a task".

It is recommended that **color categorization of informational message should be reduced to 2-3 foreground / background color combinations at most and informational messages should be assigned to a color coding with *intention* and *purpose*.**

For example, a 2 level coding mechanism could be indicative of current conditions (e.g. in manual mode) versus upcoming conditions (e.g. there is a Form A ahead).

A 3 level coding mechanism could assign one combination to Auto Control message, a second to Manual Control messages, and a third to all other message. Note that in such a case, messages associated with manual control zones should be presented with the same gray background that is currently used to represented manual control zones on the rolling map, to enhance the perceptual grouping of those elements.

Finally, note that if the explicit indication of system status is implemented (see section 4.1.1 Low Saliency of Control Mode), the AUTO CONTROL ACTIVE color coding would be redundant and could be eliminated.

Note that GRAY on BLACK may be used to indicate that action has been taken and should not be used for other informational messages.

4.1.2.4 Color Coding / Categorization of Individual Messages

If the above recommendations are not implemented, and the current color coding mechanism is retained, there are several messages that appear to be assigned incorrectly to their category as noted in the table below.

TABLE 3 – SVP MESSAGE RELATED HUMAN FACTORS CONCERNS

Braking Messages	
Message Text	**Potential Human Factors Concerns**
TARGET YYY ER	
MIN SET	
Min Set Ahead (xx)	
MIN SET NEEDED NOW (XX)	If an action is needed now, it implies a higher level of urgency, and therefore should be presented in yellow on black.
TARGET YYY ER (xx)	One of these messages flashes (see section 4.1.3 Flashing of Messages) which implies higher urgency. It should be presented in yellow on black.
TARGET YYY ER (xx)	
RELEASE AHEAD (xx)	This message implies less urgency, and therefore should be presented as green on black.
RELEASE NOW! (xx)	
BAIL OFF NEEDED! (xx)	
AIR ADVISEMENT NOT AVAILABLE	
LOW DYN BRAKING DETECTED	

Other Messages	
Message Text	**Potential Human Factors Concerns**

Other Messages	
Message Text	**Potential Human Factors Concerns**
AUTO CONTROL ACTIVE	
TRIP OPTIMIZER AVAILABLE	This is informational only and should not use a black background.
WAITING FOR PTC	This is informational only and should not use a black background.
MANUAL CONTROL ONLY	
FORM B AHEAD	A form B will require transition to manual control and therefore will require action on the part of the user. It should be green on black.
CALCULATING TRIP	
AUTO CONTROL AVAILABLE	
MANUAL CONTROL AHEAD…(##)	Switching to manual control will require an action on the part of the user, as evidenced by the timer, and therefore should be presented in green on black. Note that this is the only "informational ", message with a timer.
CURRENT TRACK UNKNOWN	
FORM A AHEAD	
AUTO ACTIVE CALCULATING…	
UNKNOWN SWITCH AHEAD	
TRANSITIONING TO MANUAL	
EXITING TRIP OPTIMIZER….	
MANUAL CONTROL NEEDED NOW! (##)	
WAITING FOR N8 (##)	
WAITING FOR MATCH… (##)	
WAITING FOR CONFIRMATION (##)	
TIMED OUT! GOING TO IDLE…	Though this does not require an immediate action on the part of the user, the urgency of the message indicates that the color coding is appropriate.
TIMED OUT! CONTROL IN IDLE	Though this does not require an immediate action on the part of the user, the urgency of the message indicates that the color coding is appropriate.
TRIP OPTIMIZER ERROR!	

4.1.3 Flashing of Messages

It is difficult to determine why some messages were chosen to flash, which involves inverting the foreground and background colors, at a rate of 200 ms.

Flashing a message increases its saliency much more so than does any other attribute, with the exception of sounding an auditory alarm or alert. This is because the human visual system easily detects light and movement in peripheral vision, whereas color changes are very poorly detected in the periphery.

The user's attention will be drawn to elements that flash much more quickly and it will be more difficult to dismiss these elements from active attention. Moreover, due to cultural conventions the user will assume that flashing elements have a higher priority than non-flashing elements.

However, this does not seem to be consistent with regards to the elements that flash, listed below:

TABLE 4 –FLASHING SVP PROMPTS

TRANSITIONING TO MANUAL
MIN SET NEEDED NOW (XX)
TARGET YYY ER (xx)
RELEASE NOW! (xx)
BAIL OFF NEEDED! (xx)
MANUAL CONTROL NEEDED NOW! (##)
WAITING FOR N8 (##)
WAITING FOR MATCH... (##)
WAITING FOR CONFIRMATION (##)
TIMED OUT! GOING TO IDLE...
TIMED OUT! CONTROL IN IDLE
TRIP OPTIMIZER ERROR!

It is recommended that flashing be used in conjunction with color, such that higher priority messages that are already presented in yellow on black also flash. Messages in other color combinations should not flash.

Note that there is also a very specific mismatch in color and flashing for the TRANSITIONING to MANUAL message. If this message is important enough to flash, it should not be presented in a neutral color combination. If it is truly just an informational message, then it should not flash.

It should also be noted that the 200 ms flash rate is too fast. The average reading speed is 200 words per minute, or 3.33 words per second. With an average message length of 3.5 words, the message will invert approximately 5-6 times while the user is attempting to read the message.

It is recommended that the rate of flashing be reduced significantly.

4.1.4 Auditory Tones

The following messages are presented with an auditory alert, the rationale for which was provided to this reviewer as, "the tone is strictly associated with air brake prompting and has no relation to SVP color/flash state".

TABLE 5 –SCP MESSAGE WITH AUDITORY ALERT

MIN SET NEEDED NOW (XX)
TARGET YYY ER (xx)
RELEASE NOW! (xx)
MANUAL CONTROL NEEDED NOW! (##)

An auditory alert is one of the most salient of attributes and should be used to ensure that the user's attention is drawn to the screen at critical times. It is generally used as the "next step elevation" when changes of color and flashing of the element are shown to be (or considered to be) inadequate.

Moreover, though there may be no intended relationship between sounding a tone and the color or flashing state of the message, the user will seek to make that association, and given the apparent unequal urgency of the colors above, will be unable to do so.

The recommendation, however, is not to change the auditory tone, but to instead change the color coding of the MIN SET NEEDED NOW and TARGET YYY ER messages to **Yellow on Black**, as recommended in section 4.1.2.4

4.1.5 Increasing Salience of Prompts Needs to Match Urgency of Action Required

When steps are taken to increase the saliency of a visual prompt, there must be a clear and unambiguous escalation of the saliency, which must also correlate to the escalation of the urgency of the prompt, as depicted in Figure 1 below.

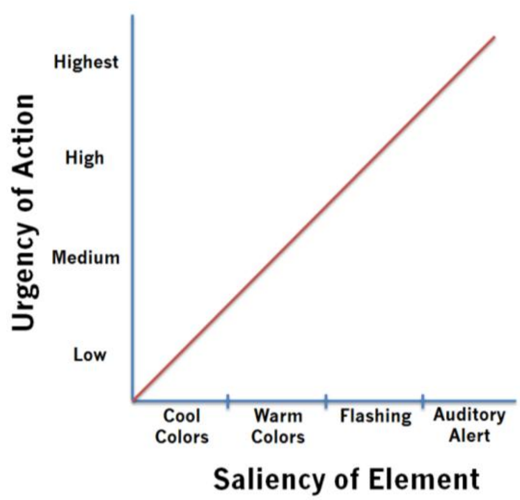


FIGURE 1: SALIENCE TO URGENCY

Changing an item's color from neutral or cool colors to warm colors increases its saliency.

Flashing the item further increases its saliency.

Sounding an auditory alert yet further increases its saliency.

Increases in saliency *must* be correlated with increasing urgency of action, from low to highest urgency.

Currently there is no clear assignment in the UI of increasing saliency to increasing urgency, as flashing and auditory tones are presented with both green and yellow prompts.

The recommendations that are presented throughout 4.1.2.4 – 4.1.2.44.1.4 serve to resolve this issue. Note that when recommendations from those sections are combined, all action oriented prompts and only action oriented prompts will be presented on a black background. Those of low urgency will be presented in green. Those with higher urgency will be presented in yellow. A subset of those presented in yellow will flash, indicating even higher urgency. A further subset of those will be accompanied by an auditory tone, indicating highest urgency of action.

4.1.6 Access to TO

When TO is operating in Standalone mode, a trip cannot be started while the train is moving. However, the engineer is able to access TO – in such cases the Welcome Screen is presented, but the New Trip button is unavailable.

This reviewer questions the ability of the engineer to access TO when a trip cannot be started. Given that there is no information available to the user on the Welcome screen, there is no advantage to accessing the screen. When a trip is not available, the Trip Optimizer button should not be available on the main AAR screen.

4.1.7 Saliency of Forced Idle

This issue has been retracted. See section 4.3 Retracted Issues.

4.1.8 Saliency of Air Brake Needed Indication

When the engineer will soon need to apply the air brake, EM presents a real-time indication on screen as an alert. However, the salience of the indication is somewhat low, as it uses a blue horizontal line across the area where the air brakes will be needed.

Consider increasing the salience of the indication by flashing the element.

Its color should not be modified given the historic use of the darker blue for air brake prompting.

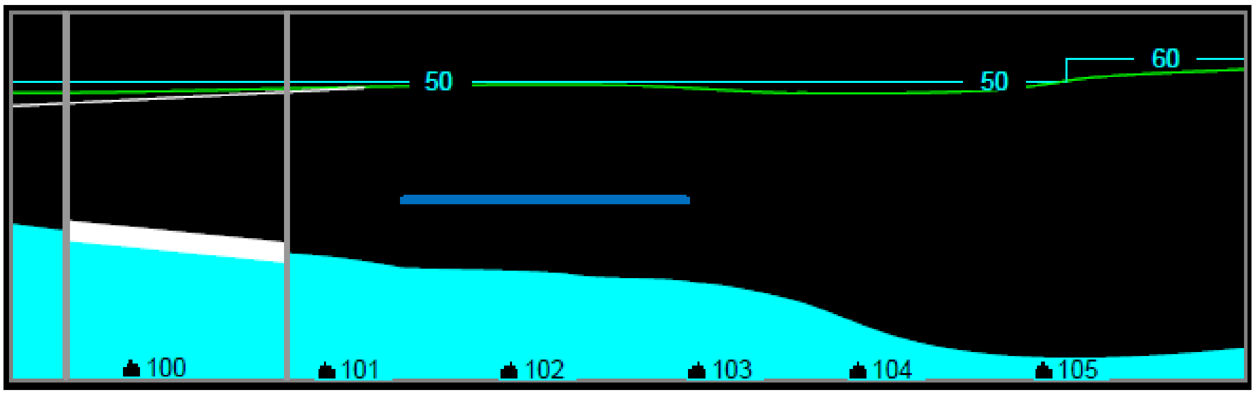


FIGURE 2: AIR BRAKE NEEDED INDICATION

4.1.9 Inadequate Operator Messages

This issue has been reclassified as a minor issue. See section 4.2 Minor Human Factors Concerns.

4.1.10 Color Coding of Auto Throttle Indicator

This issue has been retracted. See section 4.3 Retracted Issues.

4.2 Minor Human Factors Concerns

There are several minor usability issues that should be corrected, if time and resources are available to do so. These issues may minorly increase processing time and cause some annoyance to the user, but they will not significantly impact the ability of the operator to complete tasks associated with the EM screens.

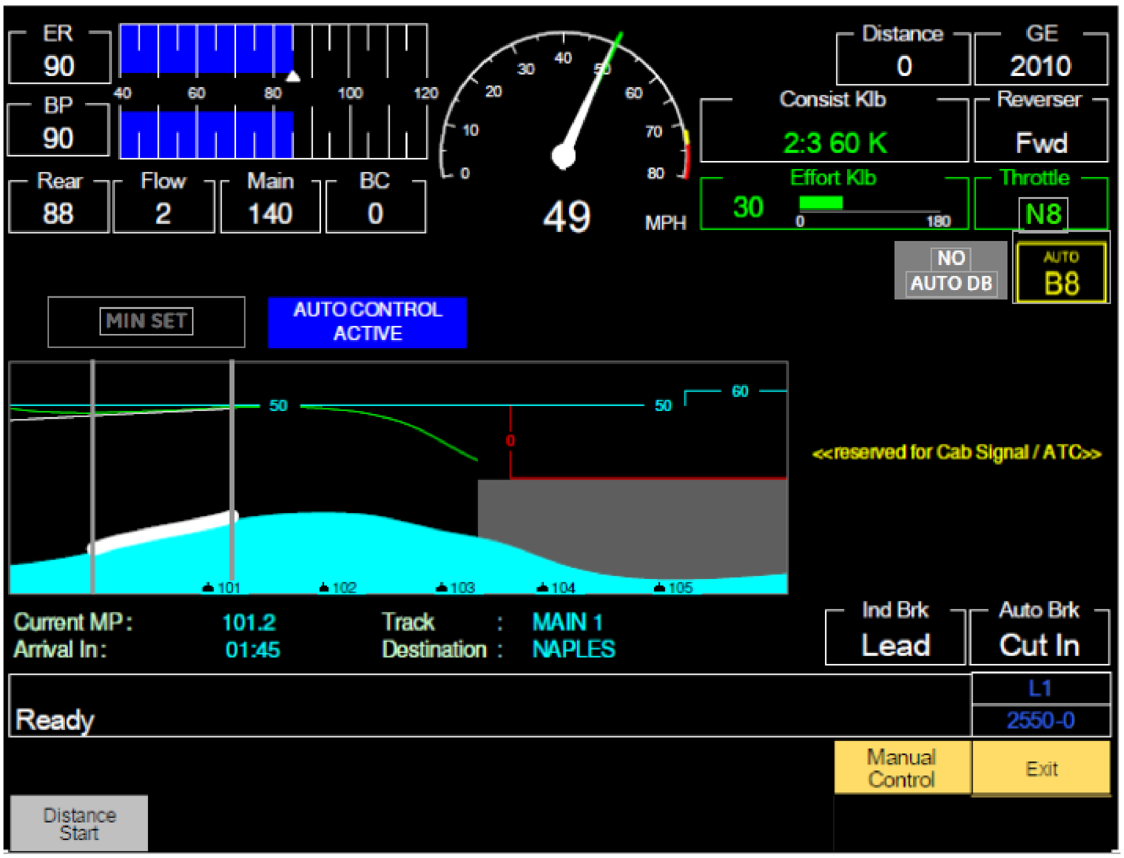
4.2.1 Color Coding and Visual Density of Speed Lines in Moving Map

This issue has been retracted. See section 4.3 Retracted Issues.

4.2.2 Low Saliency of Control Mode

EM can be operated in Auto Control and Manual Control modes, allowing the operator to maintain manual control of the throttle and dynamic braking or to relinquish control of both to the system.

The intended indicator of control mode is the presence or absence of the TO Status Indicator (present = Auto Control, absent = Manual Control).However, the saliency of this element is not as high as might be expected. While the TO indicator is the only one that can appear in its assigned space, it is one of 20+ indicators that may be present in the indicator portion of the screen (the two horizontal rows that compromise the center portion of the screen). Moreover, while its assigned position was selected based on its proximity to the Throttle indicator, this places it on the opposite side of the screen from the primary EM elements – the Rolling Map and Simple Visual Prompts.



Additional indicators of control mode include the AUTO CONTROL ACTIVE SVP, which can be overwritten, and the presence of the Manual Control button, which appears in Auto Control Mode, versus the Auto Control button that appears in Manual Mode, when conditions allow for Auto Control.

For the TO portion of the screen it is recommended that steps be made to make the control mode immediately apparent by **<u>providing an explicit indication of whether the system is in manual or auto control</u>**; one that is 1) always present, 2) always in the same location, and 3) that allows for an at-a-glance comprehension of system state. For example, altering the appearance of the train, such as coloring the train a different color when in Auto Control would be an ideal indication, as the control mode is directly associated with the train, is always present on screen and always in the same location, eliminating any need to scan for the indication.

Consider the following:

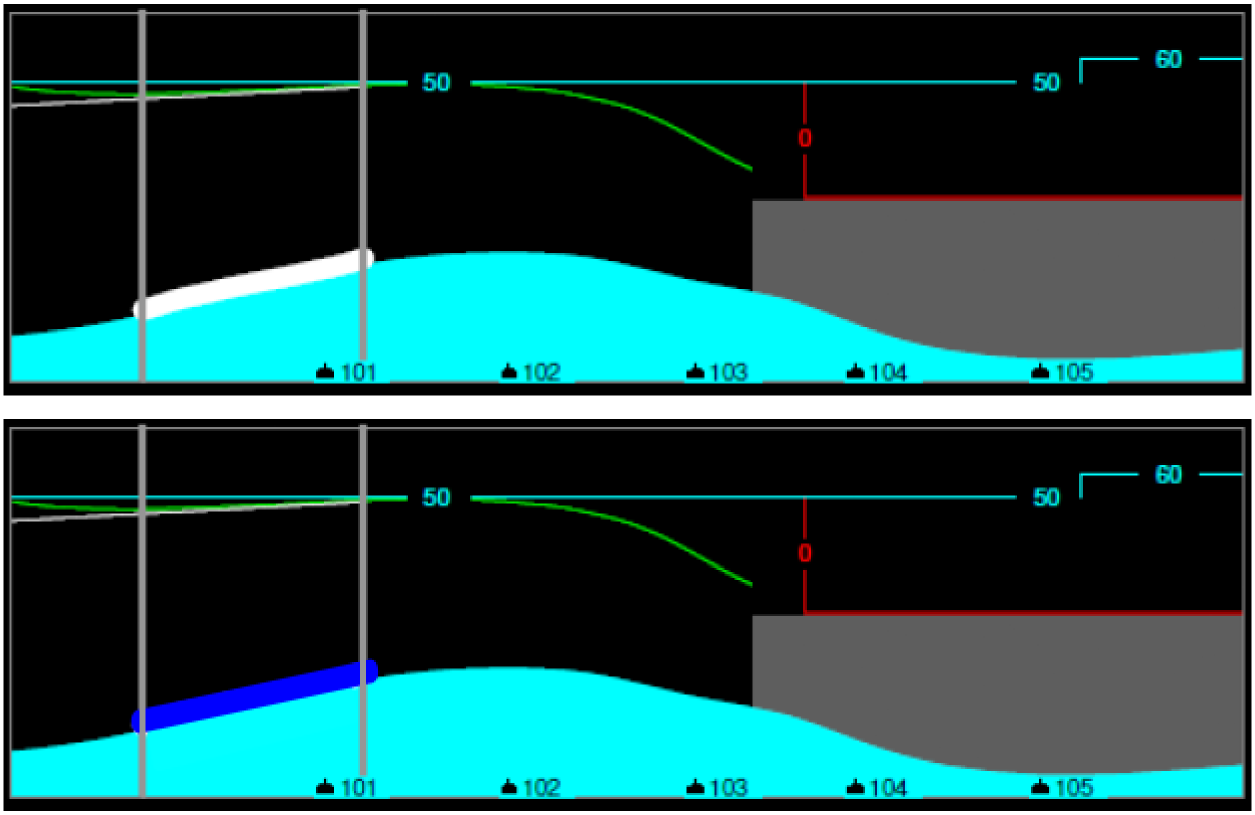


FIGURE 3: ROLLING MAP CONTROL MODE INDICATIONS (FROM TO-PTC ON GE LOCOMOTIVE DISPLAY OVERVIEW R1, PG 6)

4.2.3 Unnecessary Welcome Screen

The workflow should be revised to eliminate the Welcome Screen, combine it with the Features Acceptance screen, or alter it to provide value to the user.

The Welcome screen presented when the user presses the Trip Optimizer button from the Main Locomotive Screen (as seen in Figure 4) is unnecessary; it serves to only increase the number of steps the user must go through to start a trip and increases the amount of time that the user is away from the AAR screen.

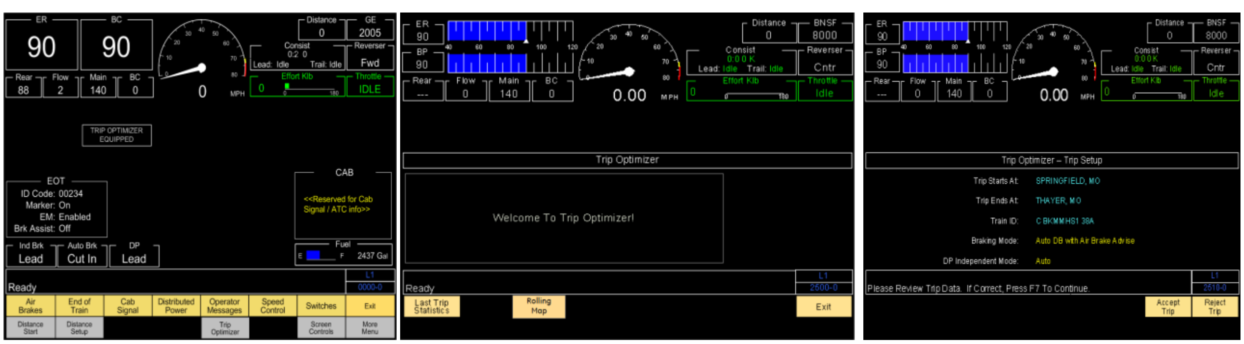


FIGURE 4: CURRENT WORKFLOW (FROM TO-PTC ON GE LOCOMOTIVE DISPLAY OVERVIEW R1)

There is no unique information provided by the Welcome screen. The only options are to Exit, should the user have entered this screen by mistake, to access the Last Trip Statistics, and to press Start TO PTC Trip or New Trip (with PTC and in Standalone, respectively), which accesses the Features Acceptance screen for the current trip.

The most frequent action in this screen will be to immediately press Start TO PTC Trip\New Trip to start Trip Optimizer; therefore that workflow should be expedited, which would be accomplished by eliminating the Welcome Screen or combining the Welcome Screen and the Features Acceptance screen, as seen below:

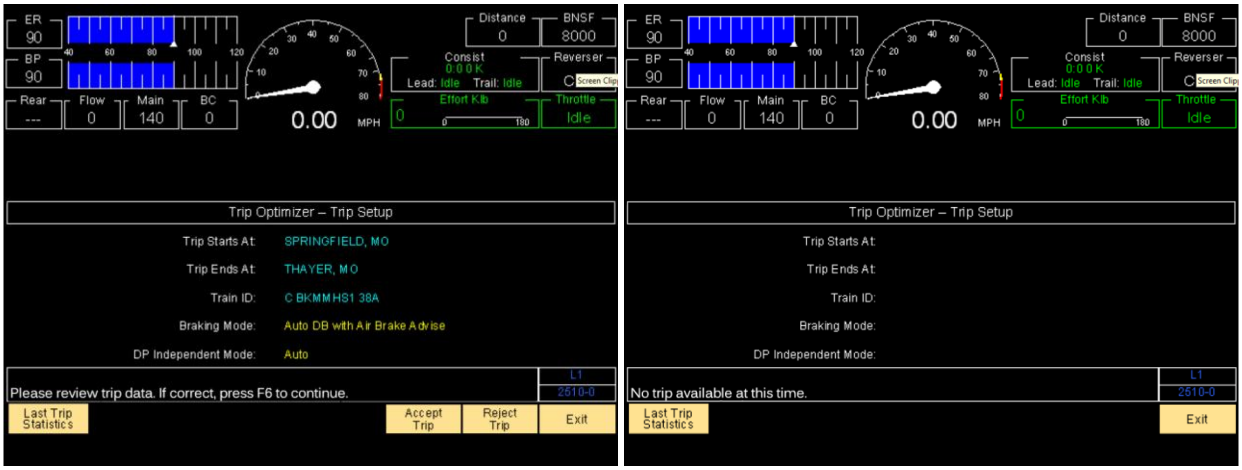


FIGURE 5 PROPOSED FEATURES ACCEPTANCE SCREEN (A – TRIP AVAILABLE / B – TRIP NOT AVAILABLE)

Should a trip not be available the Trip Setup area should be blank, a note indicating this should be provided in the Operator Messages area, and the Accept and Reject Trip buttons should be removed or grayed out).However, this reviewer questions the ability of the engineer to access the Welcome screen when a trip cannot be started (see 4.1.6 Access to TO).

Note that if the user rejects the trip, the current implementation presents a confirmation message and then returns to the Welcome Screen. Eliminating the Welcome screen or combining screens would necessitate that rejecting the trip also exit TO, a fact that would need to be added to the rejection confirmation (e.g. "Are you sure you want to reject the trip and exit Trip Optimizer?").

Note that if the user exits TO without ending the trip, when the user accesses TO again, the system goes directly to the rolling map.

4.2.4 Unnecessary Confirmation Steps

During observations of the system it was noted that both accepting and rejecting a trip lead to a confirmation that required another button press to complete the action. In these cases, the confirmation is unnecessary. Generally speaking confirmations are only required when the action cannot be recovered from. If the user accepts an erroneous trip, he has the ability to end that trip. If the user rejects a correct trip, it is this reviewer understanding that the trip will be re-presented should the user re-access the feature.

4.2.5 Salience of the Plan Speed Needle on the Speed Dial

This issue has been retracted. See section 4.3 Retracted Issues.

4.2.6 Misleading or Poorly Worded Button Labels

This issue has been retracted. See section 4.3 Retracted Issues.

4.2.7 Syntax

A great deal of evidence[2] exists, which demonstrates that reading prose is easier when capitalization is used conventionally to start sentences and to indicate proper nouns and acronyms.

Operator prompts should be presented in sentence style capitalization, while Book Title Capitalization should be used for labels.

Use of ALL CAPS is acceptable for SVP message given the need to emphasize these messages and their brevity.

4.2.8 Inadequate Operator Messages

Efforts should be made to ensure that all Operator Prompts provide adequate information as to what is expected of the user.

In the case of the Welcome Screen, the operator prompt states only "Ready", assuming that the user will understand that pressing "Rolling Map" is required to initiate a trip. If the Welcome Screen is maintained (see section 4.2.3 Unnecessary Welcome Screen), the prompt should be mode more informative – "System ready. Press F# to start the trip". (Note: this particular example has been resolved, as the button label has been changed to something more appropriate to the function. However, the remaining examples remain valid, and care should be taken to avoid introducing this issue again as the system is updated and revised).

Note that when the user ends the trip, the message "Are you sure you want to end the trip and exit TO" is presented. However, confirming End Trip does not exit TO, as the confirmation states. Instead the Welcome screen is redisplayed, showing the last trip statistics.

Similarly in the Change Locomotives screen, the prompt does not provide information to the user regarding the use of the number keys to enter the locomotive position.

4.3 Retracted Issues

The following issues were included in a draft version of this report, but further investigation and discussions with BNSF and GE Transportation have either resolved the issues or cause the issue to be retracted.

4.3.1 Saliency of Forced Idle

If the user allows a timer to elapse, in many cases the result is forced idle. The user must then move the physical throttle until the physical throttle matches the auto throttle position. The result is lost time.

When the system engages in a forced throttle, the only indication of this onscreen appears to be a flashing yellow prompt. This reviewer questions the saliency of this prompt, and question whether the engineer will be immediately aware of the forced idle.

However, in practice, given contextual cues from sound of the engine, this is likely not an issue, and will be further investigated during observations of the system.

Resolution: As expected, contextual cues within the locomotive make this condition quite salient, rendering a salient visual prompt redundant.

[2] http://www.usability.gov/sites/default/files/documents/guidelines_book.pdf

4.3.2 Color Coding of Auto Throttle Indicator

The indication of the throttle position while in Auto Control mode is shown with a green border while motoring and a yellow border when dynamic braking is active.

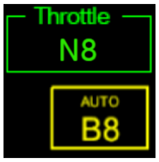


Figure 6: Throttle Indication

While this meets cultural expectations of color assignment, it does not meet the requirement from Appendix E f10 – "Design all visual displays to meet human performance criteria under monochrome conditions … and use color coding as a redundant coding technique".

Users with a red or green color deficiency will have difficulty detecting the change in the border color, as should be apparent from the reference image below (compare the green and yellow pencils for normal vision versus green or red blind/weak)

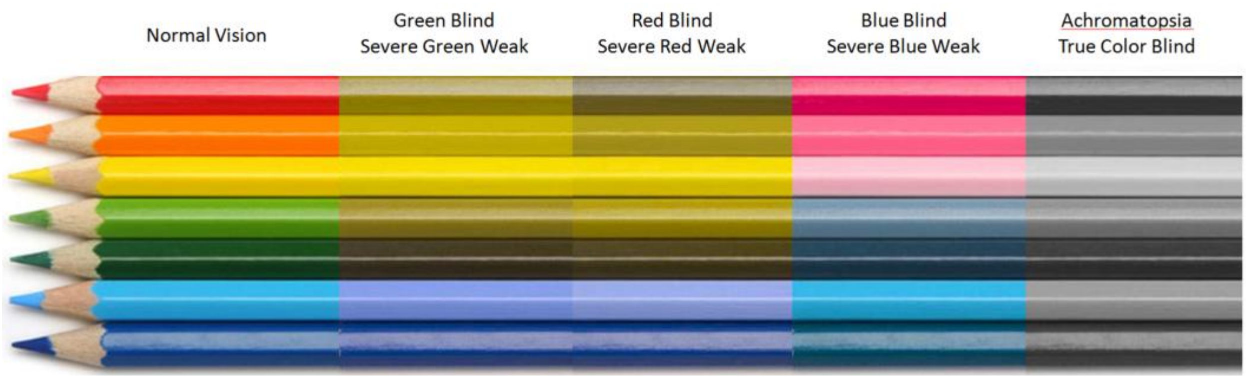


Figure 7: Color Deficiency Comparison[3]

It is recommended that another change be made to the border to distinguish between motoring and dynamic braking, such as a dashed border, a double border, or a border with a noticeably different thickness.

Resolution: This reviewer has been assured that BNSF employs tests that will detect any color weakness severe enough to disrupt perception for these colors.

However, it should be noted that Appendix E of Part 236 specifically states that color coding should only be used as a redundant coding mechanism.

4.3.3 Color Coding and Visual Density of Speed Lines in Moving Map

At the top of the moving map, there are 5 speed lines that represent various aspects of the speed, 4 of which are depicted in the image below, and which are defined in Table 6 – Speed Line Color Assignment..

[3] Image compiled from reference images available at:www.colourblindawareness.org

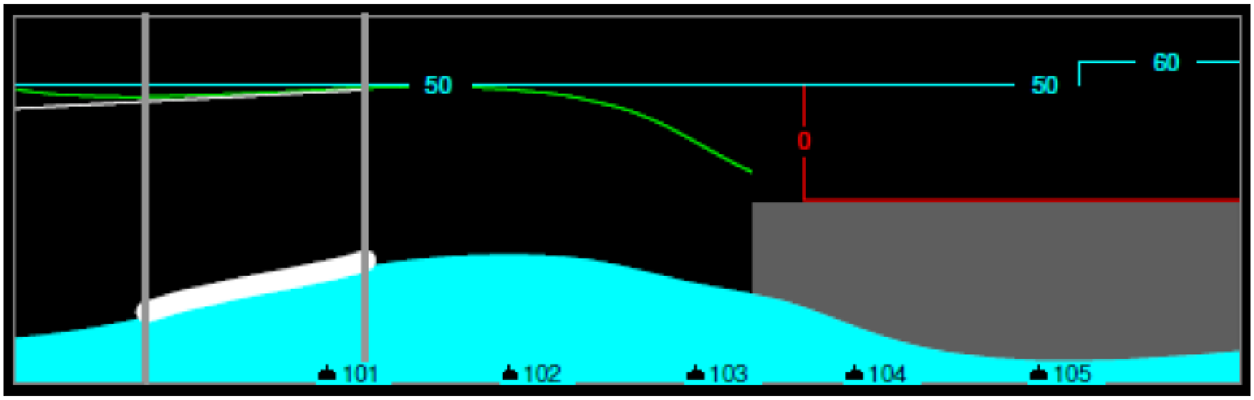


FIGURE 8: ROLLING MAP (FROM TO-PTC ON GE LOCOMOTIVE DISPLAY OVERVIEW R1, PG 6)

TABLE 6 – SPEED LINE COLOR ASSIGNMENT

	Red	Stop Target
	Yellow	Temporary Speed Restriction
	Cyan	Track Speed
	Green	Planned Speed
	White	Train Speed

For locations on that map that are at or behind the head-end of the train, the planned speed (green), train speed (white), and track speed (cyan) will likely cluster closely together. In the examples seen by this reviewer, there is little contrast between these lines, making it difficult to determine which is which. Note that the same issue is reduced ahead of the train, given that the train speed (white) is not shown.

Moreover, individuals with color deficiencies will have greater difficult differentiating these lines (see Figure 7: Color Deficiency Comparison). For those with red or green deficiencies, which are the most common, the red, yellow, and green lines will appear to be various shades of yellow. For those with a blue deficiency (more rare), yellow will be appear as a shade of pink and green will be shifted towards cyan.

It is noted that other contextual clues exist to help the user identify these lines: track speed (cyan) is a continuous step function at the top of the screen, yellow and red are both step functions that appear below the track speed line; actual and plan speed lines are smoothly-curved lines, and the actual speed appears only behind the train head end.

However, it is recommended that a different format of line should be used to represent one of these speeds. Providing a dashed line (- - -) will allow the user to differentiate the lines without relying on color or curve a key. The most likely candidate to reformat would be planned speed (green) to alleviate this issue both behind and ahead of the train.

Alternatively, consider removing the planned speed line behind the head-end. The value of the line behind the train is questionable, as it provides only feedback regarding how well the train's actual speed matched the planned speed.

Resolution: The intent is not for the user to examine any particular line, but to examine the closeness of the lines as a means of determining the achieved plan. Therefore this issue is retracted.

4.3.4 Salience of the Plan Speed Needle on the Speed Dial

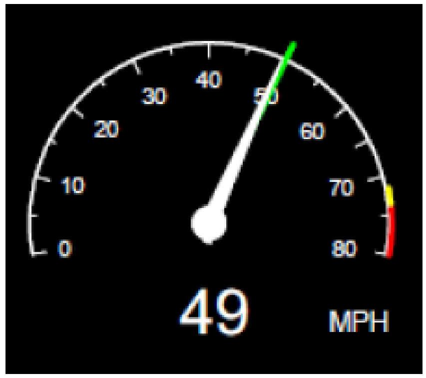


FIGURE 9: SPEED (FROM TO-PTC ON GE LOCOMOTIVE DISPLAY OVERVIEW R1, PG 6)

The salience of the plan speed needle within the speed dial will be very low when the plan and actual speeds are close to one another. While this appears to be an issue in the static screens provided in the *TO-PTC on GE Locomotive Display Overview* document, this may not be an issue in the actual use of the system given a dynamic system, which will show the actual speed and plan speed needles moving independently.

However, it should be noted that for those with red or green color weakness or blindness, this plan speed needle will appear shifted towards a dim yellow color (see Figure 7: Color Deficiency Comparison).

Consider altering the appearance of the needle to further distinguish it from the current speed needle, such as changing the thickness, adding a pattern, utilizing a different border, etc.

Resolution: The intent is not for the user to examine the plan speed needle as a separate visual element, but to observe the closeness of the needles as a means of determine the achieved plan. Therefore this issue is retracted.

4.3.5 Misleading or Poorly Worded Button Labels

The button label "Rolling Map" in the Welcome screen, when PTC is enabled on another screen, does not describe the actions that will take place upon pressing the button. Rolling Map implies that the Rolling Map feature will immediately be displayed. According to the document provided to this reviewer, Rolling Map instead presents a screen allowing the user to accept or reject the current trip information, if the trip has not already been accepted.

The recommendations made above regarding eliminating the Welcome Screen effectively eliminate this button. However, should that recommendation not be implemented, **this button label should be changed to something like "Review Current Trip" to better match the action that occurs on the button press.**

Resolution: The "Rolling Map" button was renamed to "Start TO PTC Trip", which resolves this issue. However, care should be taken to avoid introducing similar ambiguous button labels, as the system continues to be revised.

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BNSF Energy Management

Human Factors Evaluation

Separate Screen Configuration

Cognitive Workload Assessment

of

Crew Interactions with EM

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5 Cognitive Workload Assessment of Crew Interactions with EM

The primary purpose of EM is to allow the crew to optimize resources during the course of a train trip. This is done by allowing EM to control speed via the throttle and dynamic braking while in Auto Control Mode and by providing a graphical indicator of the plan speed while in Manual Control Mode.

In this implementation of EM, the UI consists of information displays and interaction components that are integrated into the existing AAR screen designed by GE Transportation. These include depictions of upcoming and preceding track (5 and 2 miles, respectively); speed and control related indications; visual prompts and messages to the operator; audible tones; and push-button controls.

EM may be run in combination with PTC (controlled and presented via a separate screen) or may be run in a standalone mode without PTC enforcement.

Regardless of the mode, the user interactions with EM primarily involve reviewing information that is pushed to the crew (e.g. prompts, graphical displays, etc.). Direct interaction with the system on the part of the engineer is required to perform the following functions as needed:

- To initiate and end Trip Optimizer (the EM feature),
- To initiate and disengage Auto Control mode.

Indirect interaction with the system occurs when prompted by the system as follow:

- Adjust throttle and speed to match plan speed while in Manual Control mode (optional),
- Adjust throttle to enter / exit Auto Control,
- To modify air brakes when prompted (EM has no connection to the air brakes).

These interactions have the potential to cause cognitive workload in addition to that already required on the part of the crew to safely operate the train and to divert the engineer's attention from the track ahead. The question to be answered is whether the tasks related to EM increase cognitive workload to the extent that the safety of the train could be compromised.

This document represents an analysis of the cognitive workload imposed on crews by the use of EM; specifically interactions of the crew with the EM system are examined in detail as part of the required Human Factors Evaluation (HFE).

5.1 Union Letters of Concern to the FRA

Both the International Association of Sheet Metal, Air, Rail, and Transportation - Transportation Division and the Brotherhood of Locomotive Engineers and Trainmen have issued letters to the FRA expressing their concerns regarding the use of Auto Control systems, such as EM, in letters dated January 21, 2016, and February 4, 2016, respectively).

Each union has expressed as their primary concern the potential of such systems to increase the operator's workload and to distract crews from their ability to monitor track conditions ahead of the train and to safety operate a moving train. Each also cites 49 CFR Part 220, which expressively forbids the use of cell phones and other electronic systems:

> A railroad operating employee shall not use an electronic device if that use would interfere with the employee's or another railroad operating employee's performance of safety relate activities.

Both unions have expressed concern regarding the mandated use of these systems by railroads, the clerical actions associated with non-use (documentation of exceptions to use), and possible disciplinary actions faced by engineers upon failure to use these systems.

A review of operating rules and procedures is beyond the scope of this analysis. This analysis focuses strictly on the use of EM as an advisory and control system, and the potential of interactions with the system to divert the engineer's attention from his primary responsibility – safely operating a moving train and monitoring track ahead of the train.

However, it should be noted that a higher level concern of BLET, that of TO screens completing with PTC operational screens for display time, does not apply to this implementation of EM, as PTC is presented on a separate screen.

5.2 Situation Awareness

Situation awareness, or situational awareness, is discussed within this document as it pertains to usability. Situation awareness refers to a person's awareness of his or her contextual environment at any given moment, including the events taking place within that environment coupled with the person's awareness of how his or her actions affect that environment. Formally, situation awareness is the "perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1988).[4] As such, situation awareness is crucial to the ability to make correct decisions and take correct actions in any given situation.

When considered within the locomotive environment, situation awareness includes: (1) the ability of the operator to maintain an awareness of the environment that exists outside of the train, ensuring that there are no obstacles in the path of the train, and (2) ensuring that the speed of the train is safe for approaching restrictions and targets, which includes maintaining an awareness of upcoming speed restrictions and targets, the current speed, and the maximum permitted speed.

5.3 Cognitive Workload Assessment Methodology

This implementation of EM is currently in a pre-installation phase, with few locomotives equipped and few crews trained in its operation. As such, empirical methods of determining cognitive workload – primary and secondary task measures and psycho-physiological measures – are not possible.

This Cognitive Workload Assessment utilizes analytical methods to determine whether interactions with EM will compromise the cognitive workload required on the part of the crew to safely operate the train, which includes maintaining situation awareness as discussed above. Analytical methods of analysis focus on decomposing the system into elemental requirements to provide an examination of the: 1) number of tasks that must be performed, 2) whether any simultaneous tasks must be performed, 3) the accuracy required by the task(s), and 4) whether there are any constraints on the completion of the task(s), as each affect cognitive workload.

Each EM task is decomposed into several operating scenarios and each is discussed in turn with regard to the cognitive workload imposed by that task in relation to the above factors.

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[4] Endsley, M. R. (2000). Theoretical underpinnings of situation awareness: A critical review. In M. R. Endsley & D. J. Garland (Eds.), Situation awareness analysis and measurement. Mahwah, NJ: LEA.

6 Train Operating Scenarios

The cognitive workload imposed on the crew for any task accomplished by interacting with EM is primarily affected by whether the task is carried out while the train is in motion or stopped. Tasks undertaken while the train is *stopped* are independent of the primary goal of the crew – that of safely operating a moving train – they do not occur simultaneously and have no time-constraints on completion; crews may take as much time as needed without affecting train safety. Therefore, tasks accomplished while the train is stopped have no impact on the operator's situation awareness or the cognitive workload required to operate a moving train.

Tasks that are accomplished while the train is in motion do have the potential to compromise the ability of the operator to maintain situation awareness and, thus, the safety of the train. These tasks are performed simultaneously with the primary task of the operator and may be time-constrained, given the need to react to upcoming speeds changes and authorities. These are discussed in detail.

6.1 Initiating Trip Optimizer

In the AAR implementation of EM, access to the Trip Optimizer Welcome screen is not restricted by train movement, though the ability of the engineer to start a trip is (see next section 6.1.1 Starting a Trip).

As noted above, should the engineer access this screen while stopped, the task cannot add to the cognitive workload required to safety operate a moving train, as the tasks are not performed simultaneously. However, the engineer currently has the ability access this screen while the train is moving for both Standalone operation and PTC operation, thus the potential for distraction is present.

When the train is moving and EM is in Standalone mode, this screen represents a dead-end. There is no information on this screen, and the only action available is to review the last trip statistics (see 6.1.2 Reviewing Last Trip Statistics). This reviewer questions the decision to allow access to the Welcome screen in these cases (Standalone + Moving). There is no benefit for diverting the engineer's attention from the track ahead.

When EM is operating with PTC, there is a benefit to accessing this screen – that of starting the trip. However, as noted below and in the Heuristics Evaluation & Cognitive Walkthrough (section 4.2.3 Unnecessary Welcome Screen and 4.2.4 Unnecessary Confirmation Steps) the process to do so should be streamlined.

6.1.1 Starting a Trip

Currently the user can start a trip under the following circumstances:

- EM Standalone / Train is Stopped
- EM + PTC / Train is Stopped
- EM + PTC / Train is Moving

When operating in EM Standalone mode, the user is required to review additional train information, including Train Setup and Restrictions. The engineer also has the ability to modify the train setup (cars, locomotive, power, etc). However, in standalone mode, access to these additional screens is restricted to when the train is stopped, and should the train move while these screen are displayed, the system reverts to the Welcome screen. Therefore, these screens cannot add to the cognitive workload of the user or distract from the primary tasks of safely operating a moving train when operating in this mode.

Similarly, should the user start a trip in the EM + PTC mode while the train is stopped, the task cannot disrupt the cognitive workload required to operate a moving train.

However, when the train is in EM + PTC mode, the engineer has the ability to start a trip while the train is moving. Doing so currently requires the user to traverse two screens and includes 4 button presses: 1) Trip Optimizer button to access the Welcome Screen, 2) New TO PTC Trip to access the Features Acceptance screen, 3) Accept button after reviewing the presented information, and 4) the confirmation of acceptance button (all remaining information will have already been validated by PTC and is not displayed or validated at the start of a trip).

The Heuristic Evaluation & Cognitive Walkthrough includes recommendations to streamline this process by combining the two screens and eliminating extra buttons presses. Should these steps be taken, only the act of reviewing information on the Feature Acceptance screen represents a task that will divert the engineer's attention from the track ahead.

In such cases, the Trip Information should already be known to the engineer; therefore validating it should not increase the cognitive workload of the operator. Moreover, should circumstances arise that require the attention of the operator, there is no system penalty involved with not responding (accepting or rejecting the trip).It is also reasonable to assume that the engineer will not attempt to engage Trip Optimizer and start a trip when his attention is required by other tasks and/or systems.

6.1.2 **Reviewing Last Trip Statistics**

At this time, it appears that the user can review the Last Trip Statistics while the train is moving.

This reviewer questions whether there are any benefits associated with reviewing the Last Trip Statistics that outweigh the potential for distraction.

The ability to review the Last Trip Statistics should be limited to when the train is stopped.

6.2 **Train Operation with EM**

The majority of interactions with EM occur while the train is at non-zero speeds and the engineer is actively engaged in the train run. These interactions will be examined below.

6.2.1 **Awareness of System State**

During Train Operation, the engineer must be aware of the current EM system state, which primarily involves determining or remembering the active control mode. The engineer should be able to recall whether the train is in Auto Control, given that only the engineer can engage Auto Control.

Should the engineer not recall the operating mode, there are several implicit means to determine system status as outlined in section 2.1.1 of the Heuristic Evaluation and Cognitive Walkthrough, and though that document provides recommendations to increase the saliency of the system state, the cognitive workload associated with maintaining or re-acquiring that awareness should be minimal as is.

6.2.2 **Train Operation in Manual Control Mode**

During train operation – while the system is in Manual Control – there are no tasks associated with the EM system. The engineer operates the train in exactly the same manner as if the EM system were not initiated; therefore the cognitive workload of the engineer during train operation EM in Manual Mode should be completely unaffected by the presence of the EM system.

6.2.3 Engaging Auto Control

During the course of a train trip, the Engineer is encouraged, though – as described to this reviewer - not required to engage Auto Control, to optimize the use of resources, by allowing the EM system to control the throttle and dynamic braking. However, the system dictates the conditions under which Auto Control can be initiated. When those conditions are not met, the controls to engage Auto Control are removed from the screen and the system provides indications that only Manual Control is available.

When Auto Control is available, the decision of whether to engaged auto control is entirely up to and initiated by the engineer. Should he decide to engage Auto Control, he selects the "Auto Control" button and follows the instructions from the EM system to place the throttle in N8. In practice, the disruption to watching upcoming tracks is limited to a single button press, as movement of the throttle is accomplished as an automatic[5] task and notch position is consistent for engaging Auto Control (always N8).

The only constraint on engaging Auto Control is associated with the countdown, in that if the engineer fails to place the throttle in N8 by the time the timer elapses, Auto Control will not engage, the system will enter a Forced Idle, and revert to Manual Control when the operator recovers from the Forced Idle.

There is minimal workload required on that part of the Engineer to accomplish these tasks; and it is reasonable to assume that the engineer will not attempt to engage Auto Control when his attention is required by other tasks and/or systems. Moreover, should circumstances arise that require the attention of the engineer – which would increase the cognitive workload associated with operating the train, the only penalty associated with allowing the Auto Control timer to elapse is to enter the Forced Idle (see 6.2.5 Responding to Forced Idle States).

Engaging auto control should not increase the cognitive workload of the operator, and the distraction to limited to a single button press.

However, should the engineer fail to successfully engage Auto Control, this reviewer questions whether the state of the system after recovery from the Forced Idle (reverting to Manual Control) will be apparent to the user. The Heuristic Evaluation and Cognitive Walkthrough provides recommendations to make the system state more apparent to the user (see section 4.1.1 Low Saliency of Control Mode).

6.2.4 Train Operation in Auto Control Mode / Responding to EM Initiated Prompts

During train operation – while the system is in Auto Control – the only EM related task required of the engineer is to monitor the EM feature for prompts and messages and to respond appropriately.

Prompts that require a response from the engineer involve modification of the air brakes, the need to disengage Auto Control, or in the case of Standalone mode, verification of the upcoming track. Other prompts involve informational message only, which do not require an immediate response.

The prompts are concise and clear, with all braking prompts presented in one message area and all other prompts presented in the other, but of which will speed processing of these messages.

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[5] Automaticity is the ability to perform practiced tasks without occupying the conscious mind with the details required, allowing the task to become an automatic response pattern. Automatic tasks (with sufficient practice) include activities such as driving a car, assembly line work, writing, reading, bicycle riding, etc..

However, as noted in the Heuristic Evaluation & Cognitive Walkthrough, the pattern of escalation of messages does not appear to correlate with the urgency of the prompts in all cases (see 4.1.5 Increasing Salience of Prompts Needs to Match Urgency of Action Required). Moreover, the current speed of flashing of some message will likely also reduce the speed of processing of those messages (see 4.1.3 Flashing of Messages). Aligning saliency with urgency will reduce the workload required to determine the correct course of action, and reducing the flashing of the message will speed processing of those messages.

If the above steps are taken, the cognitive workload required to observe these prompts would be reduced to a level that should not interfere with situation awareness or the ability to safely operate a moving train.

6.2.4.1 Disengaging Auto Control

For prompts related to the need to disengage Auto Control, such as in advance of Manual Control Zones and Form Bs, the engineer is warned in advance by the appearance of the SVP messages, and in the case of Manual Control Zones, by a graphical indicator on the Rolling Map.

In such cases, the engineer's response involves selecting the "Manual Control" button and following instructions from EM to move the throttle to the matching position before a countdown elapses. Alternatively, once "Manual Control" is selected, the engineer may instruct the system to match the current throttle position, by selecting "Current Throttle".

The only constraint associated with disengaging Auto Control involves the count-down, in that if the engineer fails to place the throttle in the matching throttle position (or to select Current Throttle) by the time the countdown elapses, the system will enter a Forced Idle state (see 6.2.5 Responding to Forced Idle States). Moving the throttle itself is an automatic task that does not impact cognitive capabilities; therefore the workload involves observing messages (see section 6.2.4 Train Operation in Auto Control Mode / Responding to EM Initiated Prompts) and 1-2 button presses.

There should be minimal workload required on that part of the Engineer to accomplish these tasks.

6.2.4.2 Air Brake Related Prompts

Other prompts require the engineer to interact with the air brakes. Again, the only constraint associated with these prompts involves the count-down, in that if the engineer fails to respond by the time the countdown elapses, the system will enter a Forced Idle state (see 6.2.5 Responding to Forced Idle States).

6.2.4.3 Other Action Prompts

Other prompts, which can only appear in Standalone mode, require the engineer to respond to a question regarding the upcoming trip (e.g. the track to take after a switch), the response for which should already be known to the engineer and which involves a single button press.

There should be minimal workload required on that part of the Engineer to accomplish these tasks.

6.2.4.4 Informational Messages

Information messages do not require a response from the engineer, and the only workload / distraction involves reading the prompt, which should not affect cognitive workload given their concise natures. However, the

Heuristic Evaluation & Cognitive Walkthrough provides recommendations to speed the processing of these messages, by color coding all information messages in the same manner.

Moreover, it is recommended that each message be carefully evaluated to determine whether the message is in fact necessary. Those that are not, should be eliminated.

6.2.5 Responding to Forced Idle States

Should the engineer fail to respond to prompts from the EM system, the system will enter a forced idle state. The system will idle the engine and disengage Auto Control mode, and the engineer must move the throttle position to match, before being able to engage the engine again. There is no cognitive workload associated with moving the throttle position; engineers do so as an automatic task, which does not impact cognitive capabilities.

There may be a small amount of workload associated with determining why the EM enforced the Idle State, should the user choose to do so. Given the above prompts, the cause of the forced idle should be readily apparent to the engineer. However, the cause of the forced idle is largely irrelevant, in that the engineer is not required to determine this, and the actions required remain the same regardless of the cause of the forced idle.

Therefore responding to a forced idle state should not impact the cognitive workload of the engineer.

6.2.6 Manually Disengaging Auto Control

In addition to the system prompting the engineer to disengage Auto Control, the engineer may choose to disengage Auto Control mode manually.

The tasks, consequences, and workload involved in doing so are identical to those in 6.2.4.1 Disengaging Auto Control. Moreover, it is reasonable to assume that the engineer will not attempt to disengage Auto Control when his attention is required by other tasks and/or systems.

6.2.7 Exiting / Re-entering Trip Optimizer (Trip in Progress)

The Engineer can choose to exit and re-enter Trip Optimizer during the course of the train run, in order to access other locomotive functions without ending the trip. Should the user choose to exit TO, the Exit button is available in Manual or Auto Control Mode, which will immediately exit TO.

To re-enter TO, the user selects the "Trip Optimizer" button, as in 6.1 Initiating Trip Optimizer; however, the system will immediately redisplay the Rolling Map.

Each of these actions represents a single button press, and will, therefore, not add to the cognitive workload already experienced by the engineer.

6.3 Ending a Trip

The Engineer may choose to end the trip. Operationally, this should be done only at the end of the trip. Doing so requires the selection and confirmation of the "End Trip" button, and can only be accomplished from the Manual Control Mode. Selection and confirmation while the train is at zero speed can have no impact on the cognitive workload associated with the safe operation of a moving train.

This button can also be selected at non-zero speeds, as a means to exit the trip should TO enter into a failed state that renders it non-functional. Doing so requires two button presses: selection and confirmation. It is also reasonable to assume that the engineer will not attempt to end the trip when his attention is required by other tasks and/or systems. Should circumstances arise that require the attention of the engineer – which would increase the cognitive workload associated with operating the train, there is no penalty associated with not confirming the End Trip selection.

7 Conclusions

EM is primarily a display component that requires little interaction on the part of the engineer. When interaction is required, it is primarily in the form of reading the display and responding to prompts from the system. The information in the display is presented in a clear and concise manner that allows for rapid processing and no confusion on the part of the engineer. Responding to prompts generally involves activities that are external to the EM system and which can be performed with automaticity on the part of the crew (and thus require no cognitive workload).

There are no time- or attention-intensive tasks associated with EM. Those with modest time and/or attention requirements (e.g. initializing EM and starting a trip) can only be completed while the train is at zero speed, and thus have no impact on the cognitive workload required on the part of the crew to safely operate the train or the crew's ability to maintain situation awareness.

The EM feature should not interfere with the crew's ability to maintain situation awareness while operating a moving train, nor should any interactions with the system impact the cognitive workload required on the part of the crew to safely operate the train.

However, the concerns of the unions as discussed in 5.1 Union Letters of Concern to the FRA should not be dismissed. This review is limited to examining crew's interactions with the EM system as an advisory and auto control interface. Actions associated with EM that are external to EM system interactions, such as recording exceptions to EM use, as noted by the Union letters, are beyond the scope of this review.

Likewise, operating rules that mandate the use of EM in all possible instances may influence the behavior of the engineer, encouraging him to interact with EM when doing so may not be advisable, such as when other circumstances arise that require the attention of the engineer.

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BNSF Energy Management

Human Factors Evaluation

Separate Screen Configuration

Analysis

of

Appendix E of 49 CFR Part 236 Subpart I

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8 Appendix E to Part 236—Human-Machine Interface (HMI) Design

The following addresses Appendix E of 49 CFR Part 236 with regards to the design of the user interface (UI) of the Energy Management (EM) feature. The primary purpose of EM is to allow the crew to optimize resources during the course of a train trip. This is done by allowing EM to control speed via the throttle and dynamic braking while in Auto Control Mode and by providing a graphical indicator of the plan speed while in Manual Control Mode.

The UI consists of information displays and interaction components that are integrated into the existing AAR screen designed by GE Transportation. These include depictions of upcoming and preceding track (5 and 2 miles, respectively); speed and control related indications; visual prompts and messages to the operator; audible tones; and push-button controls.

The following responses primarily relate to the design of the EM UI, though aspects of the workstation design and hardware are discussed, where appropriate. This Human Factors Evaluation (HFE) focuses only on EM; the remaining components of the AAR screen are outside the scope of the project.

(a) This appendix provides human factors design criteria applicable to both subpart H and subpart I of this part. HMI design criteria will minimize negative safety effects by causing designers to consider human factors in the development of HMIs. The product design should sufficiently incorporate human factors engineering that is appropriate to the complexity of the product; the gender, educational, mental, and physical capabilities of the intended operators and maintainers; the degree of required human interaction with the component; and the environment in which the product will be used.

(b) As used in this section, "designer" means anyone who specifies requirements for—or designs a system or subsystem, or both, for—a product subject to subpart H or subpart I of this part, and "operator" means any human who is intended to receive information from, provide information to, or perform repairs or maintenance on a safety-critical product subject to subpart H or I of this part.

(c) Human factors issues the designers must consider with regard to the general function of a system include:

(1) Reduced situational awareness and over-reliance. HMI design must give an operator active functions to perform, feedback on the results of the operator's actions, and information on the automatic functions of the system as well as its performance. The operator must be "in-the-loop." Designers must consider at a minimum the following methods of maintaining an active role for human operators:

(i) The system must require an operator to initiate action to operate the train and require an operator to remain "in-the-loop" for at least 30 minutes at a time;

Response: Use of EM is not required for train operation and use of EM in no way negates the responsibility of the operator to remain "in-the-loop", to operate the locomotive according to operating rules, and to be aware of the environment outside of the train.

The EM feature primarily displays information to the crew, though direct interaction with the system on the part of the engineer is required to perform the following functions as needed:

- To initiate and end Trip Optimizer (the EM feature),
- To initiate and disengage Auto Control mode.

Indirect interaction with the system occurs when prompted by the system as follow:

- Adjust throttle and speed to match plan speed while in Manual Control mode (optional),
- Adjust throttle to enter / exit Auto Control,
- To modify air brakes when prompted (EM has no connection to the air brakes).

(ii) The system must provide timely feedback to an operator regarding the system's automated actions, the reasons for such actions, and the effects of the operator's manual actions on the system;

Response: The only automatic functions within the EM feature are as follows:

- EM can be placed in Auto Control, in which the system will control speed via the "virtual" throttle position (the physical position of the throttle is always N8) and dynamic brakes.
- EM can fail to transition to Auto Control due to a lack of response from the engineer, in which case it will enter a Forced Idle state.
- EM can automatically disengage Auto Control and enter a Forced Idle state, due to lack of response from the engineer.

To place the system in Auto Control, the engineer selects Auto Control push-button and places the throttle in N8, as prompted. If the engineer fails to place the throttle in N8, the system will enter a Forced Idle. When the user recovers from the Forced Idle, the system will remain in Manual Control Mode. Though contextual cues will be available to the engineer regarding the shift back to Manual Control, the *Heuristic Evaluation and Cognitive Walkthrough* recommends increasing the saliency of the control mode by altering the appearance of the train graphic in the Rolling Map when in Manual Control versus Auto Control (see 4.1.1 Low Saliency of Control Mode).

While the system is in Auto Control Mode an indicator is always present that provides feedback regarding the "virtual" position of the throttle. No action is required on the part of the engineer and the system does not provide feedback regarding the reasons for shifting the throttle or braking; however, training and experience on the part of the crew provides the understanding of the rationale.

While in Auto Control, the need will often arise for the system to shift back into Manual Control, such as when approaching a manual control zone. In such cases an indication appears on the Rolling Map when the train is 2 miles from the zone and prompts appear to alert the engineer for the need to shift control modes. Should the engineer fail to respond, the system will enter a Forced Idle state, in which the system automatically idles the engine, and the engineer must move the throttle until the physical throttle position matches. When a Forced Idle occurs the status should be obvious to the user based on contextual cues.

EM may require the engineer to modify the air brakes, as the system has no connection to the air brakes. In such cases, again prompts and messages appear to alert the engineer to the need; and should the engineer fail to respond, the system enters the Forced Idle state.

Other automated actions include communication between EM and other system components, which either do not directly affect the crews' actions or, if they do, are indicated via a prompt.

(iii) The system must warn operators in advance when it requires an operator to take action;

Response: With regard to EM, the only actions that the system requires on the part of the engineer are to modify the air brakes when requested to by the system, to adjust the throttle position to smoothly transition between control modes, and in Standalone mode to respond to prompts regarding the upcoming path of the train.

When the air brakes are required, the system alerts the engineer with prompts and messages. The prompts increase in saliency as the need for the air brakes increases – changing from green to yellow in color, along with the addition of flashing and tones, where appropriate.

Should the engineer fail to respond, EM will enter the Forced Idle state.

Adjusting the throttle position is necessary only when transitioning between control modes.

A shift from Manual Control to Auto Control can only be initiated by the engineer and only at times permitted by the system. The only action required by the engineer once the "Auto Control" button is selected is to shift the throttle to N8. Should the engineer fail to comply, the system will enter a Forced Idle, and return to Manual Control after the operator recovers from the Forced Idle. Though contextual cues will be available to the engineer regarding the shift back to Manual Control, as mentioned above, the *Heuristic Evaluation and Cognitive Walkthrough* recommends increasing the saliency of the control mode.

The shift from Auto Control to Manual Control can be initiated by the system or by the engineer. When the system requires the transition from Auto Control to Manual Control prompts are provided to alert the engineer in advance of the need to transition and operator messages provide instructions to change the throttle position. When the engineer initiates the transition, similar prompts and messages appear to guide the transition. Should the engineer fail to comply, the system will enter the Forced Idle state.

(iv) HMI design must equalize an operator's workload; and

Response: The primary action of the engineer while in Auto Control is to monitor the EM display for prompts, messages, and indicators of upcoming manual control zones or the need for air brakes. Prompts clearly convey the action required on the part of the engineer and are presented with graphical components that convey the urgency of the prompt. However, the *Heuristic Evaluation and Cognitive Walkthrough* provides recommendations to modify the prompts for further clarity (see 4.1.5 Increasing Salience of Prompts Needs to Match Urgency of Action Required).

The primary EM-related action of the engineer while in Manual Control is to optionally adjust the speed of the train based on the plan speed presented on the Rolling Map and the delta between the plan and current speeds on the speed dial. There is no requirement to do so. However, should the engineer choose to, the Rolling Map and Speed Dial graphical displays allow for an at-a-glance determination of the recommended speed and upcoming recommended speed.

A cognitive workload assessment has been performed on the EM interface. See the Cognitive Workload Assessment for further information.

(v) HMI design must not distract from the operator's safety related duties.

Response: EM is intended only to enhance the crew's use of resources during the course of a train run and does so by controlling the throttle and dynamic brakes while in Auto Control, and by providing only implicit speed recommendations while in Manual Control (by presenting the planned speed as a line on the Rolling Map and as a separate needle on the speed dial).

The system is designed to do so without imposing on the cognitive workload of the crew, by presenting all information in a clear and concise format. However, as the *Heuristic Evaluation and Cognitive Walkthrough* provides recommendations to modify the prompts for further clarity.

As described above, the primary action of the engineer while in Auto Control is to monitor the EM display for prompts, messages, and indicators, which clearly convey the action required on the part of the engineer.

There are no interactions required on the part of the engineer while in Manual Control.

In both operating modes, the train operator continues to be responsible for the safety of the train, railroad employees, civilians, and equipment, and continues to be responsible for train handling according to operating rules.

A cognitive workload assessment has been performed on the EM interface. See the Cognitive Workload Assessment for further information.

(2) Expectation of predictability and consistency in product behavior and communications. HMI design must accommodate an operator's expectation of logical and consistent relationships between actions and results. Similar objects must behave consistently when an operator performs the same action upon them.

Response: The EM feature requires very few actions on the part of the engineer: adjusting the throttle position when necessary to transition between control modes, initiating the transition between control modes, adjusting the air brakes when prompted, and responding to simply prompts. Of these, the only actions that directly manipulate EM interface are the push buttons controls to initiate Trip Optimize , to transition between control modes, and to respond to simple questions.

The results of the button presses are consistent with user expectations, in that the button labels generally accurately convey the result of button selection. However, the *Heuristic Evaluation and Cognitive Walkthrough* provides recommendations to eliminate or re-label buttons that do not clearly convey the resulting action. Modifying these will eliminate any issues; however, should these recommendations not be implemented, the result will be a negligible decrement in usability that will not ultimately impact usability when a train run is active.

Adjusting the throttle and air brakes will indirectly affect the EM, in that the prompts indicating these actions are needed will be removed, as is an expected result of complying with instructions.

The system as also designed to support crew's existing mental models and rules of operation and work processes by the use of established railroad iconography and terminology.

(3) End user limited ability to process information. HMI design must therefore minimize an operator's information processing load. To minimize information processing load, the designer must:

(i) Present integrated information that directly supports the variety and types of decisions that an operator makes;

Response: There are few decisions that the engineer must make during use of to the EM feature. While in Manual Control the engineer will continue to operate the train as thought EM were not active. The engineer may choose to model train control to comply with the plan speed line presented on the Rolling Map. However, should he choose to do so, the only necessary action will be to glance at the screen to determine the recommended speed, which is provided graphically.

While in Auto Control mode, the only decisions required of the engineer are to determine when to modify the Air Brakes or to transition from Auto Control Mode to Manual Control Mode. The system has been designed to alert the engineer in advance to the need for either action via prompts, messages, and graphical displays on the Rolling Map. In either case, should the engineer not comply, the system will initiate a forced-idle state.

(ii) Provide information in a format or representation that minimizes the time required to understand and act; and

Response: The integrated nature of the Rolling Map and its associated information minimizes the time required to understand this information, providing at a glance indications on the Rolling Map of the need to modify the air brakes or to transition from Auto Control Mode to Manual Control Mode.

When an action related to the air brakes is required, the system also alerts the crew via an auditory tone.

(iii) Conduct utility tests of decision aids to establish clear benefits such as processing time saved or improved quality of decisions.

Response: The Rolling Map was based on the track line map of ETMS developed for BNSF by Wabtec, for which utility tests were conducted.

The graphical speeds rings are based on those widely used in the transportation industry to depict speed.

(4) End user limited memory. HMI design must therefore minimize an operator's information processing load.

(i) To minimize short-term memory load, the designer shall integrate data or information from multiple sources into a single format or representation ("chunking") and design so that three or fewer "chunks" of information need to be remembered at any one time.

Response: Operation with EM adds no memory requirement; there is no need for the operator to recall information to any extent greater than that required for operation without EM. Further, there is no operational information that is exclusive to EM use.

The only exception is the need for the operator to remember how to activate the EM feature, which currently involves selecting the Trip Optimizer button to access the Welcome screen, selecting the New TO PTC Trip button to view trip information, and accepting the trip. Note that the *Heuristic Evaluation and Cognitive Walkthrough* recommends removing the Welcome screen and reducing the activation sequence; however, maintaining the current implementation has no impact on user memory requirements.

(ii) To minimize long-term memory load, the designer shall design to support recognition memory, design memory aids to minimize the amount of information that must be recalled from unaided memory when making critical decisions, and promote active processing of the information.

Response: There is no long term memory load associated with the use of the EM feature other than understanding its operation, which is consistent for operating procedures already known to the engineer.

(d) Design systems that anticipate possible user errors and include capabilities to catch errors before they propagate through the system;

Response: While the system is in use, it is not possible for the crew to introduce errors into EM. User input into the system is required only to initiate EM and its associated Rolling Map display.

At EM initiation, the system presents the trip information, which the engineer either rejects or accepts. If the trip information is incorrect, which is highly unlikely, the engineer should reject the trip and contact the dispatcher. The incorrect status of the trip information should be obvious to the engineer, as an incorrect destination would be presented.

(1) Conduct cognitive task analyses prior to designing the system to better understand the information processing requirements of operators when making critical decisions; and

Response: The EM Rolling Map was based on a previous system, I-ETMS, for which a Human Factors Analysis (HFA) was conducted and submitted to the FRA. That HFA included contextual observations of I-ETMS, interviews and observations with train crews, an analysis of the system, and a cognitive workload assessment. Issues detected during that evaluation have been remedied or otherwise addressed.

EM was also subject to *Heuristic Evaluation & Cognitive Walkthrough* and *a Cognitive Workload Assessment*. Recommendations have been provided to remedy any issues detected.

(2) Present information that accurately represents or predicts system states.

Response: The Rolling Map accurately represents the current MP of the train, the elevation of the track, and the speed of the train as it compares to the planned speed and track speed. It also provides information regarding the track elevation, plan speed, and speed restrictions 5 miles ahead of the train, as well as upcoming air brake requirements and manual control zones.

The system also provides a real time display of the delta between the plan speed and the actual speed of the train on the speed dial.

(e) When creating displays and controls, the designer must consider user ergonomics and shall:

(1) Locate displays as close as possible to the controls that affect them;

Response: The EM feature is integrated into the AAR screen. The engineer interacts with the feature via push-button type controls that are located directly below the soft key representations on the screen.

(2) Locate displays and controls based on an operator's position;

Response: The EM feature is integrated into the AAR screen, which already exists in the locomotive workstation, and which has been proven in use.

(3) Arrange controls to minimize the need for the operator to change position;

Response: The EM feature is integrated into the AAR screen, which already exists in the locomotive workstation, and which has been proven in use.

(4) Arrange controls according to their expected order of use;

Response: Very few controls are required to use EM. The engineer directly interacts with the push-button controls for EM only to initiate or exit the system, to start or end a trip, and to transition between control modes. Within each task there is no associated expected order of use to the buttons.

(5) Group similar controls together;

Response: As per the above, there are very few direct controls required to operate EM, and each is provided only when applicable, creating the associated group.

(6) Design for high stimulus-response compatibility (geometric and conceptual);

Response: The primary action taken in response to stimuli provided by EM (visual displays, prompts, operator messages, and auditory alerts) is to adjust the throttle or to modify the air brakes; the actions for which are taken using established train controls external to EM that are compatible with the expectations and previous experience of the operator.

Other responses involve transitions between control modes, when necessary, which are accomplished by push-button type controls.

(7) Design safety-critical controls to require more than one positive action to activate (e.g., auto stick shift requires two movements to go into reverse);

Response: There are no safety critical controls associated with EM. Controls that will end the trip, thereby eliminating the benefit of EM, require a confirmation prior to execution.

(8) Design controls to allow easy recovery from error; and

Response: The EM feature, when used in conjunction with PTC, is an information only display and requires no input from the operator. The only "error conditions" that are possible are the failure to successfully transition between control modes and the failure to respond to prompts.

When transitioning from Manual Control to Auto Control, should the engineer fail to shift the throttle to N8, the system will enter a Forced Idle and revert to Manual Control after recovery from the Forced Idle. The engineer will simply need recover from the Forced Idle and re-initiate the transition.

When transitioning from Auto Control to Manual Control, should the engineer fail to shift the throttle as instructed, the result will be a Forced Idle state.

Should the engineer fail to respond to other prompts, the result is also a Forced Idle state.

When used in standalone mode, the engineer is able to modify train information (e.g. locomotives, power mode, train data, setout/pick up cars). Appropriate error checking is programmed into the system to avoid the introduction of errors, where possible. The user must also confirm the changes that have been made, allowing the user to catch any errors that may have been introduced.

Other errors may include erroneous button selection. There are few buttons associated with EM; however the possibility of an erroneous button press exists. In all cases, error recovery is possible with 1-2 buttons presses.

(9) Design display and controls to reflect specific gender and physical limitations of the intended operators.

Response: EM is gender neutral. In regards to physical limitations, the FRA requires certification and licensing for locomotive engineers. Certification includes being in acceptable physical condition and meeting vision and hearing acuity standards. EM is designed for an individual with normal or corrected-to-normal vision and auditory abilities.

(f) The designer shall also address information management. To that end, HMI design shall:

(1) Display information in a manner which emphasizes its relative importance;

Response: As previously mentioned, the most important information for the operator to be aware of is the upcoming need to transition from Auto Control to Manual Control or to modify the Air Brakes.

In both cases a graphical indicator appears on the Rolling Map, which is further emphasized by the appearance of an associated prompt, presented with escalating saliency elements: changes from green to yellow, added flashing of the prompt and added audible indicators, as appropriate.

However, the *Heuristic Evaluation and Cognitive Walkthrough* highlights this reviewers concern that other prompts that utilizes the same foreground and background colors reduce the effectiveness of the prompts, and provides recommendation to better correlate increasing prompt saliency with increasing urgency of action required.

(2) Comply with the ANSI/HFS 100–1988 standard;

Response:

Section 1 – 4: Purpose, General Scope, Conformance Policy, and Cited Standards are not applicable.

Section 5: Installed Systems
Incorporation of the EM feature into the AAR screen requires no structural changes to the physical workstation of the operator

Section 6: Input Devices
The input mechanism for the AAR has been proven in use. Input consists of push-button controls arranged in 2 horizontal rows directly below the screen. Additional buttons along the side of the unit allow the operator to control brightness and contrast for the LCD screen, but are not used for data input.

EM is not controlled by any other external input, such as a mouse, tablet, digital pen, or touch screen. Thus, subsections specifying requirements for other types of input devices are not applicable to this interface.

As proven in use, button force and displacement are adequate for the average operator and provide sufficient tactile feedback. There is no need for a button-lock feature because the system does not require tasks with prolonged or continuous button depression.

Physical buttons are not labeled themselves because the button function changes depending on the screen displayed. Soft button labels are mapped to the same row and position on screen as the physical button. A label is displayed when a button is associated with an action and absent when the button serves no current function. Labels are written in sans serif font in title format to increase readability.
EM will be integrated into an existing screen within the front instrument panel or console. Therefore, several issues discussed in this section are not applicable, including the stability and unintentional movements of the device, grip surfaces, edges, and corners of the device; and the handedness of the operator.

Section 7: Visual Displays
The equipment that comprises the AAR Screen is proven in use and meets the requirements regarding: Viewing and Spatial Characteristics, Temporal Quality, Luminance & Color Quality and Information Format.

Section 8: Furniture

As indicated previously, the addition of EM will not change the current operator physical workstation or furniture in any significant manner.

(3) Utilize a display luminance that has a difference of at least 35cd/m2 between the foreground and background (the displays should be capable of a minimum contrast 3:1 with 7:1 preferred, and controls should be provided to adjust the brightness level and contrast level);

Response: The equipment that comprises the AAR Screen is already proven in use, and controls are provided to adjust both the brightness and contrast levels of the display to an operator's preferred level.

(4) Display only the information necessary to the user;

Response: The information provided by EM is not necessary to safely operate the train and use of the EM feature is not required, though it is encouraged by BNSF operating rules. When in use the information that is presented (elevation, upcoming restrictions, prompts regarding upcoming braking requirements) is either relevant to operating the train under Manual Control or is relevant to how the system is controlling the train under Auto Control.

(5) Where text is needed, use short, simple sentences or phrases with wording that an operator will understand and appropriate to the educational and cognitive capabilities of the intended operator;

Response: Standard railroad phrases well known to crews were used to convey information in an understandable and recognizable format. Phrases and words used are appropriate for the educational and cognitive capabilities of the operator.

(6) Use complete words where possible; where abbreviations are necessary, choose a commonly accepted abbreviation or consistent method and select commonly used terms and words that the operator will understand;

Response: Abbreviations were avoided when possible, and where used, are either consistent with approved railroad abbreviations, commonly accepted, or are identified (e.g. "DYN" for dynamic, MIN, and ER).

(7) Adopt a consistent format for all display screens by placing each design element in a consistent and specified location;

Response: The main EM components of the feature use a fixed layout design. The Rolling Map is displayed continuously while the trip is in progress, unless EM is exited by the engineer, and updates in real time to display upcoming track conditions. Prompts and operator messages can appear over the course of the trip; however, the placement of each type remains consistent.

(8) Display critical information in the center of the operator's field of view by placing items that need to be found quickly in the upper left hand corner and items which are not time-critical in the lower right hand corner of the field of view;

Response: EM displays information that assists the operator in resource management; it does not display critical information for safe train operation. However, information that is of higher priority within EM (prompts) is displayed in the top-left corner of the screen space reserved for EM.

EM does not interfere with the display of critical information that is external to EM; which continues to be displayed along the top third of the screen.

(9) Group items that belong together;

Response: All information that relates to upcoming track characteristics is presented in the integrated Rolling Map. Prompts are grouped above the Rolling Map, with trip information below the Rolling Map and operator messages presented below that. The remaining information presented by EM is integrated into the existing displays, with a planned speed line presented on the existing speed dial, and when in Auto Control an indication of the virtual throttle position is displayed directly below the indicator of the physical position.

(10) Design all visual displays to meet human performance criteria under monochrome conditions and add color only if it will help the user in performing a task, and use color coding as a redundant coding technique;

Response: Within the EM interface color is used to distinguish the 5 speed lines that can appear on the Rolling map. These are as follows:

- Red = stop target
- Yellow = speed restriction
- Cyan = track speed
- White = train speed
- Green = plan speed

While color is the primary coding mechanism used to differentiate these lines, other contextual clue exist that allow the engineer to identify each without the color, and the *Heuristic Evaluation & Cognitive Walkthrough* provides a recommendation to further differentiate the plan speed line.

Color is also used as a redundant coding mechanism to group prompts into related categories. However, this reviewer finds that improvements can be made to these categorizations. The *Heuristic Evaluation & Cognitive Walkthrough* provides recommendations to clarify and simplify the use of color as a categorization coding mechanism.

Color is also used to distinguish between motoring and dynamic braking while in Auto Control Mode, via the border of the Virtual Throttle indicator (i.e. yellow for braking and green otherwise). These colors are industry standard to indicate these modes, however, recommendations have been made in the *Heuristic Evaluation and Cognitive Walkthrough* to combine color with another physical attribute of the border to ensure color is used as a redundant coding mechanism.

(11) Limit the number of colors over a group of displays to no more than seven;

Response: The use of non-neutral colors in EM is limited to 5 colors: red, green, yellow, cyan, and blue, which are also used in the overall AAR screen. Therefore, EM does not add to the number of colors already used in the display.

(12) Design warnings to match the level of risk or danger with the alerting nature of the signal; and

Response: Commonly used color coding is utilized in the main screen to signify the severity of encountered conditions. Yellow and red represents conditions that require attention from the operator, such as upcoming speed restrictions and stops, and prompts of higher urgency.

Moreover, audible alerts of increasing perceived urgency are utilized for events of increasing severity.

(13) With respect to information entry, avoid full QWERTY keyboards for data entry.

Response: Information entry is only possible within EM when used in Standalone mode and utilizes push button controls to navigate fields and numbered buttons to modify the data..

(g) With respect to problem management, the HMI designer shall ensure that the:

(1) HMI design must enhance an operator's situation awareness;

Response: Situation awareness refers to a person's awareness of his or her contextual environment at any given moment, including the events taking place within that environment coupled with the person's awareness of how his or her actions affect that environment. When considered within the locomotive environment, situation awareness includes the ability of the operator to maintain an awareness of the environment that exists outside of the train, ensuring that there are no obstacles within the path of the train and ensuring that the speed of the train is safe for approaching restrictions and targets, which includes maintaining an awareness of the upcoming mandatory directives and targets.

As an advisory and auto control system EM was designed to require minimal physical, visual, and cognitive interaction to avoid disrupting situation awareness on the part of the crew.

All information is available at-a-glance, with saliency cues designed to allow the engineer to interpret the urgency of the information with minimal processing time. However, note that, as discussed above, the *Heuristic Evaluation & Cognitive Walkthrough* provides recommendations to clarify and simplify salience cues, as well as other recommendations to decrease processing time required for prompts and to reduce key presses, where possible

(2) HMI design must support response selection and scheduling; and

Response: The system avoids all time and attention intensive tasks.

Response selection is supported by designing to the established rules of operation where possible, including terminology and the types of responses required for those operating rules.

(3) HMI design must support contingency planning.

Response: The only contingency plan necessary for EM is in response to a failure of the feature. If the system detects a failure that prevents use of the feature, a prompt and message of higher priority is presented to the engineer and the Rolling Map feature will be removed. The crew will continue to operate the train either with PTC enabled or according to establish operating rules.

Crews are responsible for maintaining safe train operation according to operating rules. The absence of the system has no impact on these responsibilities.

(h) Ensure that electronics equipment radio frequency emissions are compliant with appropriate Federal Communications Commission regulations. The FCC rules and regulations are codified in Title 47 of the Code of Federal Regulations (CFR).

Responses: This section is irrelevant to the design of the user interface of EM.

(1) Electronics equipment must have appropriate FCC Equipment Authorizations. The following documentation is applicable to obtaining FCC Equipment Authorization:

Responses: This and remaining sections are irrelevant to the design of the user interface of EM.

(i) OET Bulletin Number 61 (October, 1992 Supersedes May, 1987 issue) FCC Equipment Authorization Program for Radio Frequency Devices. This document provides an overview of the equipment authorization program to control radio interference from radio transmitters and certain other electronic products and an overview of how to obtain an equipment authorization.

(ii) OET Bulletin 63: (October 1993) Understanding The FCC Part 15 Regulations for Low Power, Non-Licensed Transmitters. This document provides a basic understanding of the FCC regulations for low power, unlicensed transmitters, and includes answers to some commonly-asked questions. This edition of the bulletin does not contain information concerning personal communication services (PCS) transmitters operating under Part 15, Subpart D of the rules.

(iii) 47 Code of Federal Regulations Parts 0 to 19. The FCC rules and regulations governing PCS transmitters may be found in 47 CFR, Parts 0 to 19.

(iv) OET Bulletin 62 (December 1993) Understanding The FCC Regulations for Computers and other Digital Devices. This document has been prepared to provide a basic understanding of the FCC regulations for digital (computing) devices, and includes answers to some commonly-asked questions.

(2) Designers must comply with FCC requirements for Maximum Permissible Exposure limits for field strength and power density for the transmitters operating at frequencies of 300 kHz to 100 GHz and specific absorption rate (SAR) limits for devices operating within close proximity to the body. The Commission's requirements are detailed in parts 1 and 2 of the FCC's Rules and Regulations (47 CFR 1.1307(b), 1.1310, 2.1091, 2.1093). The following documentation is applicable to demonstrating whether proposed or existing transmitting facilities, operations or devices comply with limits for human exposure to radiofrequency RF fields adopted by the FCC:

(i) OET Bulletin No. 65 (Edition 97–01, August 1997), "Evaluating Compliance With FCC Guidelines For Human Exposure To Radiofrequency Electromagnetic Fields",

(ii) OET Bulletin No 65 Supplement A, (Edition 97–01, August 1997), OET Bulletin No 65 Supplement B (Edition 97–01, August 1997) and

(iii) OET Bulletin No 65 Supplement C (Edition 01–01, June 2001).

(3) The bulletin and supplements offer guidelines and suggestions for evaluating compliance. However, they are not intended to establish mandatory procedures. Other methods and procedures may be acceptable if based on sound engineering practice.

[75 FR 2720, Feb. 15, 2010]

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BNSF Energy Management
Human Factors Evaluation
Separate Screen Configuration

Ergonomic Analysis
of
AAR Screen and CDU Placement

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9 Ergonomic Analysis of AAR Screen and CDU Placement

There are two implementations of the EM feature in BNSF locomotives. The first integrates the EM feature into the AAR Screen HMI, which already exists within the locomotive workstation. The second integrates the EM feature into the PTC CDU HMI, which is being added to these locomotives.

This document examines the placement of the AAR screen and the CDU in relation to the working position of the engineer. This analysis is based on images and dimensions provided by BNSF (included in this report), which detail the position of these displays and their associated controls in each cab layout. To this reviewer's understanding, these images represent a comprehensive set of AAR screen and CDU placements for the BNSF Railway.

9.1 Ergonomic Considerations

An analysis of the design of the entire locomotive workstation used by train crews is beyond the scope of this document. However, these workstations, having already been approved for use, are assumed to comply with ANSI/HFS 100–1988 Human Factors Engineering of Computer Workstations. Only changes to the physical workstation due to the integration of the CDU and the existing location of the AAR screen will be examined for their potential to impact compliance with ANSI/HFS 100.

Assessing display placement involves examining how the user will interact with these displays and the position of these displays in regards to the seated reach envelope and the field of view of the operator from a seated position, as described later in this document.

9.1.1 User Interactions with Controls/Display

With regard to EM functions, the engineer is expected to periodically visually review the contents of the display and physically react with changes to throttle position and air brakes and to physically interact with push button controls adjacent to the display, when necessary, regardless of the implementation used.

9.1.2 Seated Reach Envelope

The seated reach envelope is the space accessible to a person for manipulation of controls from a seated position. The placement of a control is guided by two factors: 1) frequency of use of the control and, 2) type of control.

Generally, controls that are used frequently should be within the extended reach envelope of the full arm as depicted by the gray areas below. Controls that have a very high frequency of use should be within the normal reach envelope, depicted as white space in this image.

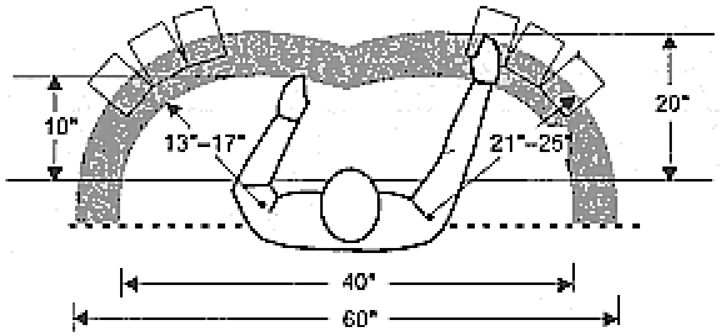

FIGURE 1: HORIZONTAL REACH ENVELOPES (ADAPTED FROM NIOSH)[6]

Push button controls of the type used for the CDU and AAR screen allow for greater range of placement, including extending beyond the extended reach envelope into the maximum working distance, which provides another 4-5 inches of reach and is easily accessible by extending the shoulder forward (not pictured above).

Push button controls can also extend into areas to the side of and slightly behind the user, up to the limit of arm travel (approximately 130°). Note that the use of chairs that swivel, such as those used with locomotive workstations, further extends the limit of arm travel.

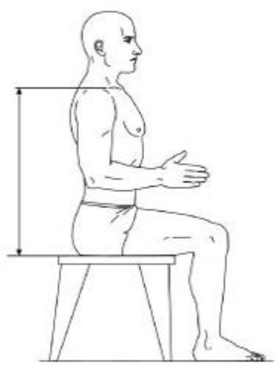

FIGURE 1: SITTING SHOULDER HEIGHT

With regards to the vertical height of the work space, the sitting shoulder height of adults (as measured from the sitting surface) ranges from 20.0 – 25.4 inches, for 5th percentile females – 95th percentile males, respectively[7].

Sitting shoulder height is relevant to the height of the display (measured at the midline), as frequently used controls are recommended to be placed below shoulder height to reduce arm fatigue.

Given the above, controls for the AAR screen and CDU that will be used while the train is in motion and the operator is expected to remain seated should ideally be placed below shoulder height and within approximately 30 inches of the operator.

However, it should be noted that the majority of intensive interactions between the engineer and the EM feature (validation and modification of trip information, standalone implementation only) take place while the train is stopped and the operator is not required to remain seated at the workstation.

---

[6] Measurements shown are those for the 50th percentile adult, or the average adult (https://www.purdue.edu/ehps/rem/safety/ergo.htm)

[7] *1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics.* Anthropology Research Project, Inc. Yellow Springs, Ohio 45387

9.1.3 **Field of View**

The binocular field of view in the horizontal plane extends approximately 120° (see image below). Vision is sharp only in foveal areas, a fairly small area directly ahead of each eye when facing to the front. The user must turn his/her eyes and/or head to place objects in the foveal area. Eyes generally turn about 30° horizontally before the head must also be turned, which can comfortably give a further 45° view to either side.

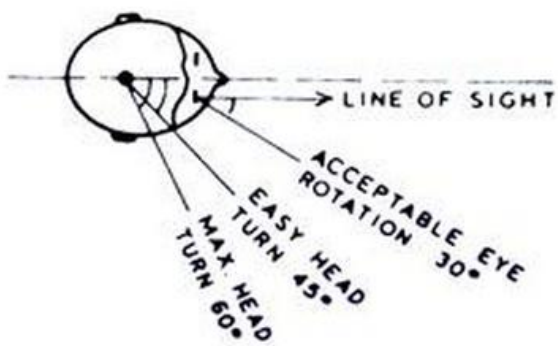

FIGURE 1: FIELD OF VIEW[8]

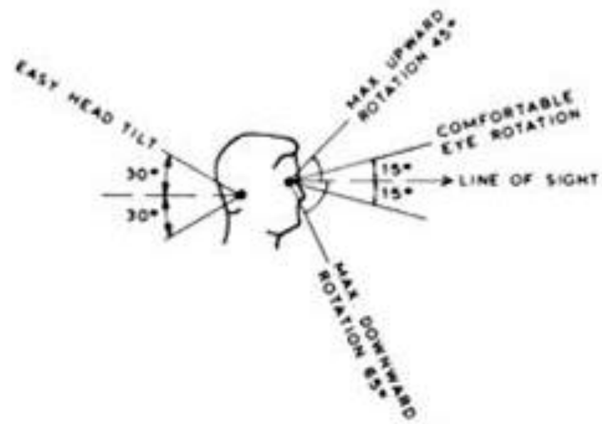

FIGURE 2: VERTICAL FIELD OF VIEW[3]

In the vertical plane, eye movements are comfortable within 15° above or below the line of sight, and the head can easily incline 30° upward or downward. Thus, by movement of head and eye, the operator has an extended direct field view.

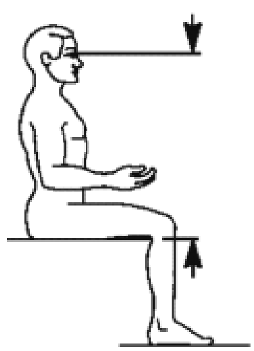

FIGURE 1: SITTING EYE HEIGHT

With regards to the vertical height of the display, the sitting eye height of adult ranges from 27.0 – 33.4 inches (5th percentile female – 95th percentile male)[9]. The CDU and AAR screen do not need to be placed directly in line with the sitting eye height, but this measurement should be taken into consideration with regards to the amount of eye and head rotation that may be required to read the display.

Note that placement of the displays should also support a display angle that is near perpendicular to the operator's line of sight to ensure maximum visibility and readability of the display.

[8] Peacock, B. & Karwowski, W (1993). *Automotive Ergonomics*. Taylor and Francis.

[9] *1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics.* Anthropology Research Project, Inc. Yellow Springs, Ohio 45387.

9.1.4 Peripheral Vision

With regards to peripheral vision, changes to color and motion can be detected depending on the type of change and where in the peripheral vision that change is presented.

Changes in motion can be detected in the entire range of horizontal peripheral vision (104° to the direct line of sight on the same lateral side of the head). Changes in color can be detected up to 30° horizontally from the direct line of sight. Vertically, the limit of color vision is approximately 25° above and 30° below the direct line of sight, whereas motion can be detected 50° above and 70° below the line of sight.[10]

9.2 Screen Placements

There are two locomotive layouts in use by BNSF that will have the EM feature added to the current design.

9.2.1 Desktop Style Control Stand

This workstation configuration is used in the Dash-9 locomotive. Both the CDU and one of the AAR screens are directly to the front of the engineer when seated and facing the windshield and are integrated into the existing workstation. The second AAR screen is to the front left of the operator, integrated into the workstation, and angled to face the operator's chair.

FIGURE 1: DESKTOP STYLE CONTROL STAND – VIEW 1

[10] *Parameters of Human Vision and Viewshed Definition.* www.stockyardhillwindfarm.com.au/pdf/PPAR_Annexes/ATS/Annexes/Annex_J/AnnexJ-LVA_PART_12.pdf

FIGURE 1: DESKTOP STYLE CONTROL STAND – VIEW 2

TABLE 7 –MEASUREMENTS FOR DASH-9

PROVIDED	Height	Distance from Operator
CDU	36.5″ floor to midline	34.0″
Main AAR Screen	36.5″ floor to midline	34.0″
Sitting Surface	22.0″ (surface to floor)	n/a

CALCULATED	Viewing Angle[11]	Reaching Distance
CDU	21.6° – 33.8° (downward)	28.3″
Main AAR Screen	21.6° – 33.8° (downward)	28.3″

Viewing angle and reaching distance were calculated as described below and illustrated in the following images from the measurements provided, which were for that of a near 95th percentile male.

- The vertical distance of the display midline from the line of sight was calculated as follows: sitting eye height + measure sitting surface height from floor – measured display height from floor.
- The viewing angle and reaching distance were calculated based on: right-triangle assumption of line of sight to vertical distance of display from line of sight, calculated vertical distance, diagonal line from nose to midline of display (the hypotenuse).

[11] Measured for 95th percentile male; extrapolated for 5th percentile female.

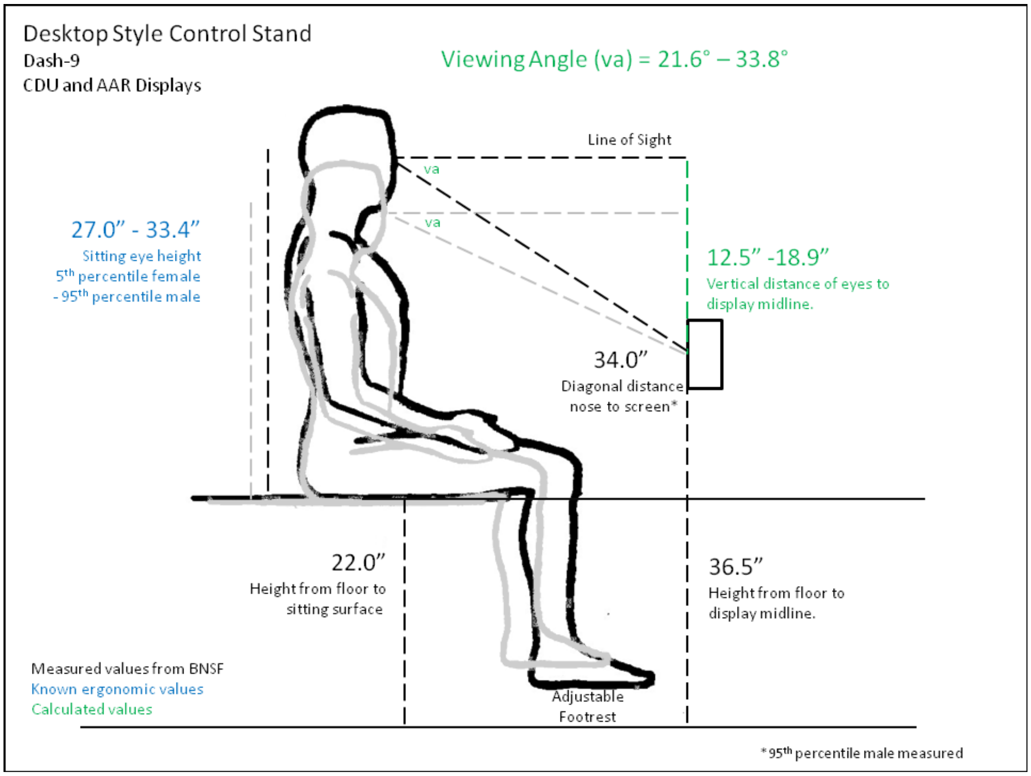

FIGURE 1: DESKTOP STYLE CONTROL STAND, DASH-9, AAR AND CDU DISPLAY – VIEWING ANGLE

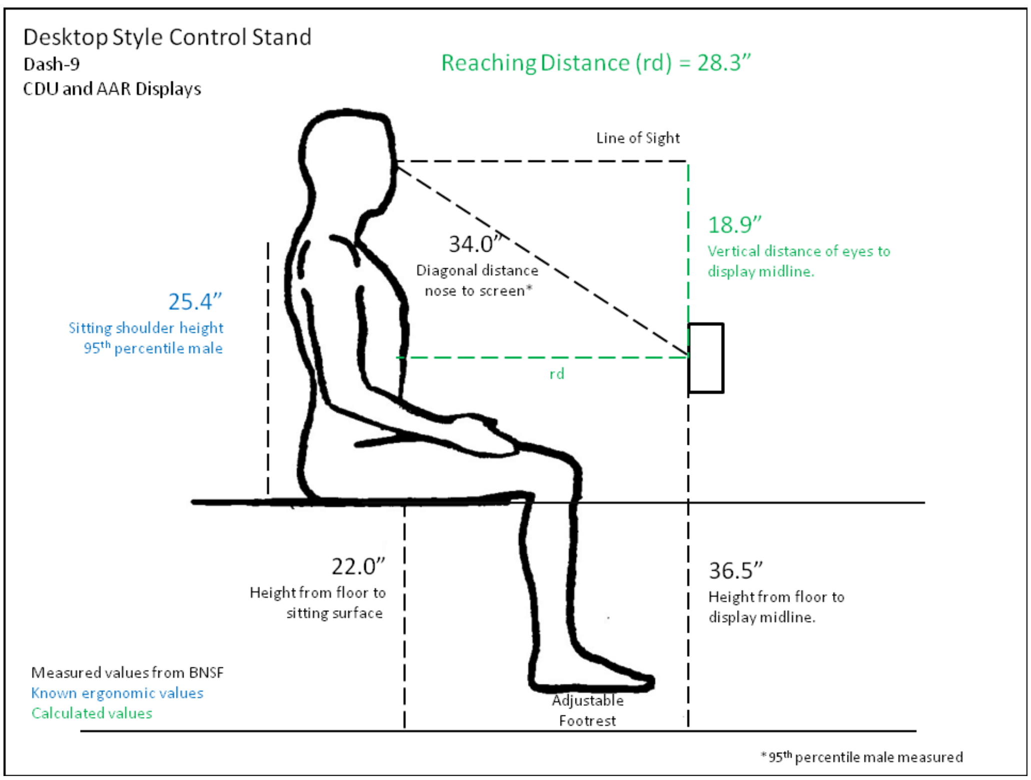

FIGURE 1: DESKTOP STYLE CONTROL STAND, DASH-9, AAR AND CDU DISPLAY – REACHING DISTANCE

From an ergonomic perspective, this is ideal in terms of viewing the displays. All screens are well within the field of view of the operator, and the CDU and one AAR screen are in the line of sight out the front windshield without obstructing the view out the windshield or of other equipment.

The midline height the both screens is 14.5 inches above the sitting surface, causing viewing angle of 21.6 – 33.8° below the operator line of sight (dependant on operator height), and both screens are located directly in front of the operator. For all operators, the viewing angle is well within maximum levels of eye rotation, or within comfortable eye rotation when combined with an easy tilt of the head downward.

For the second AAR screen, depending on how close the operator sits to the screen, the screen can be brought into foveal view by acceptable horizontal eye rotation or at most, an easy turn of the head.

These locations are also ideal for detecting prompts presented by EM, regardless of the screen they are presented on (integrated into the AAR or the CDU), as all screens remain within the portion of peripheral vision in which color changes and motion (flashing) are detected.

Though the push buttons to respond to and control the screens exceed the normal and extended reach envelope, they are within the maximum reach envelope and well below shoulder height for even small operators. Given that physical interactions with the CDU and the AAR screens, as related to EM, will be infrequent while the train is in motion, this is acceptable.

9.2.2 AAR Style Control Stand

This workstation configuration is used in the C4 and ES44Ac/DC locomotives. In this configuration both AAR screens are directly to the front of the engineer when seated and facing the windshield, and both are integrated directly into the operator workstation. The CDU is placed to the left-front of the engineer, is angled to face the operator's chair, and is installed as an extension to the workstation.

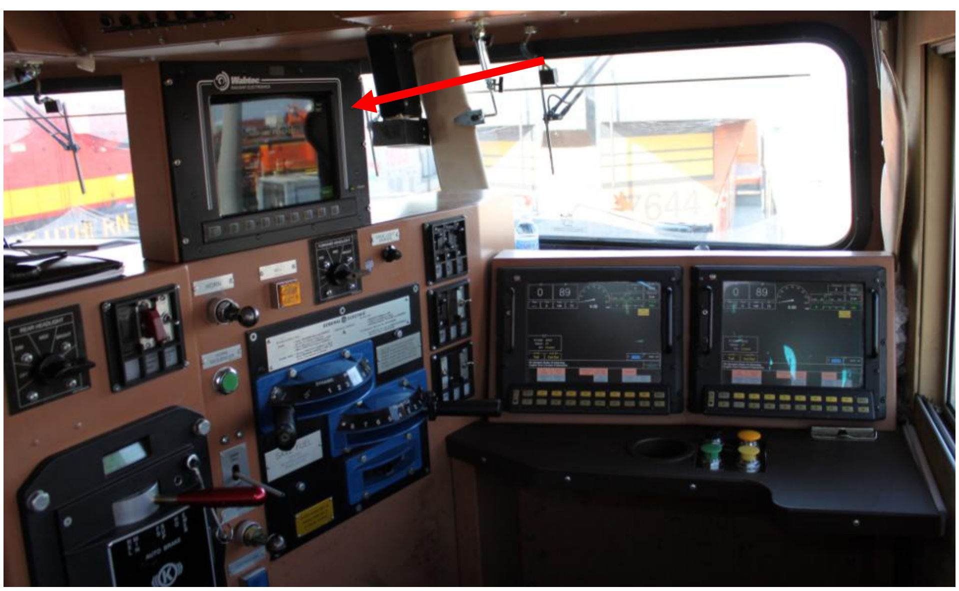

FIGURE 1: AAR STYLE CONTROL STAND – VIEW 1

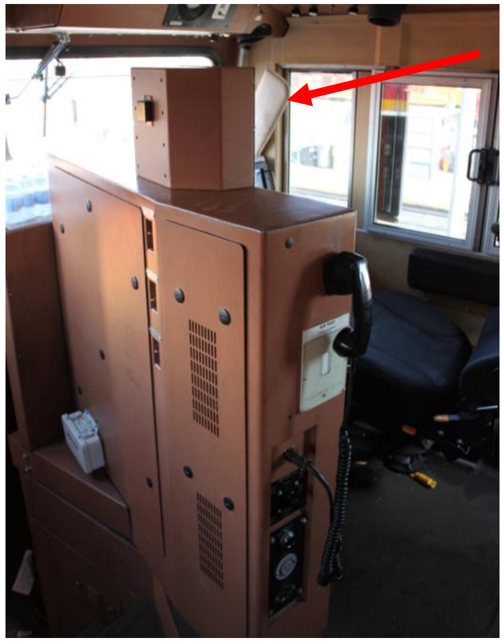

FIGURE 1: AAR STYLE CONTROL STAND – VIEW 2

TABLE 8 – MEASUREMENTS FOR C4

PROVIDED	Height	Distance from Operator
CDU	45.0″ floor to midline	22.0″
AAR Screen 1	36.0″ floor to midline	31.0″
Sitting Surface	22.0″ (surface to floor)	n/a

CALCULATED	Viewing Angle	Reaching Distance
CDU	7.4° – 19.6° (downward)	19.4″
Main AAR Screen	24.8° – 38.7° (downward)	24.2″

TABLE 9 – MEASUREMENTS FOR ES44AC/DC

PROVIDED	Height	Distance from Operator
CDU	50.0 floor to midline	24.0″
AAR Screen 1	36.0″ floor to midline	31.0″
Sitting Surface	22.0″ (surface to floor)	n/a

CALCULATED	Viewing Angle	Reaching Distance
CDU	2.39° (upward) – 13.0° (downward)	23.4″
Main AAR Screen	24.8° – 38.7° (downward)	24.2″

Viewing angle and reaching distance were calculated as described above.

9.2.2.1 AAR Screens

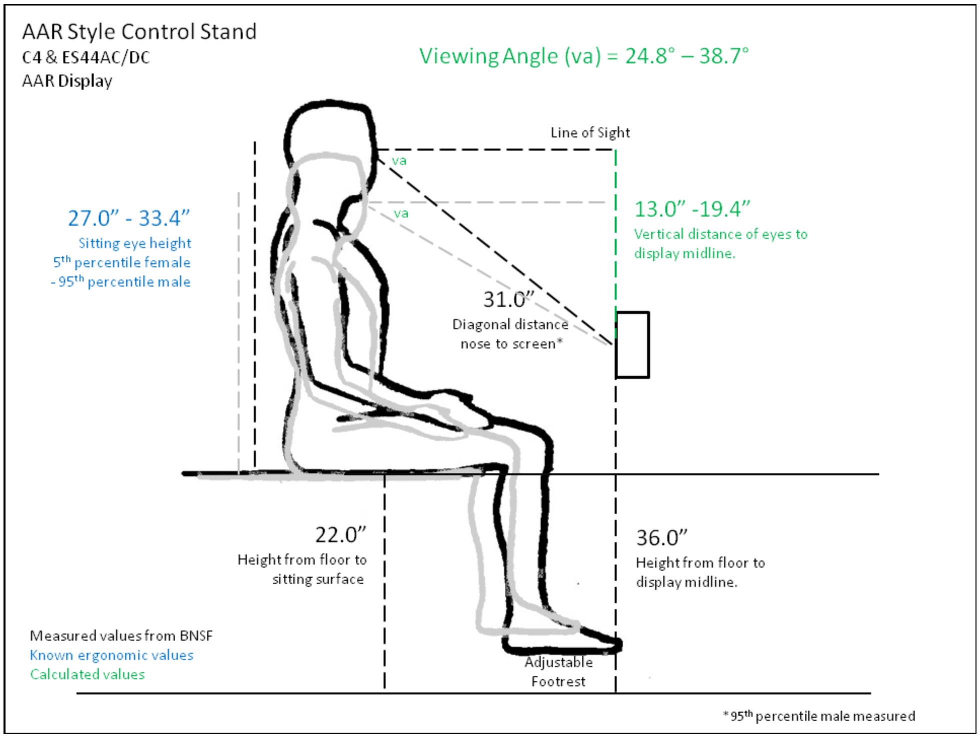

FIGURE 1: AAR STYLE CONTROL STAND, C4 & ES44AC/DC AAR DISPLAY – VIEWING ANGLE

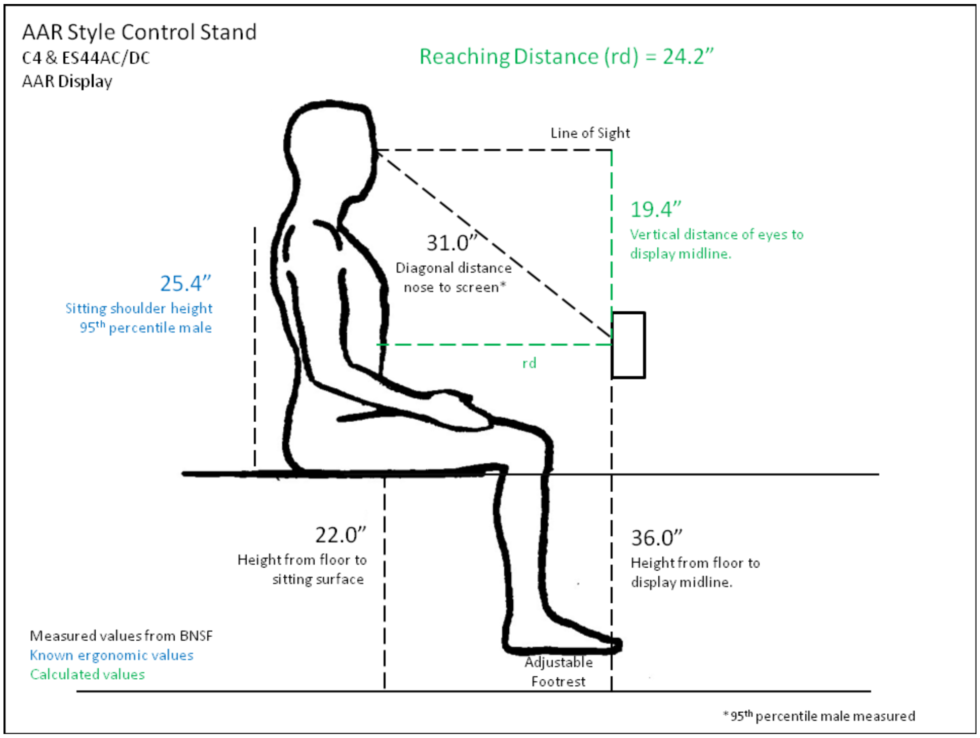

FIGURE 1: AAR STYLE CONTROL STAND, C4 & ES44AC/DC AAR DISPLAY – REACHING DISTANCE

For the AAR implementation of EM, from an ergonomic perspective, the position of the AAR screens is ideal in terms of viewing the displays. They are well within the field of view of the operator and are in the line of sight out the front windshield without obstructing the view out the windshield or of other equipment.

The midline height the screens is 14.0 inches above the sitting surface, causing viewing angle of 24.8-38.7° below the operator line of sight (dependant on operator height), and both screens are located directly in front of the operator. For all operators, the viewing angle is well within maximum levels of eye rotation, or within comfortable eye rotation when combined with an easy tilt of the head downward.

These locations are also ideal for detecting prompts presented by EM on the AAR screens, as they are within the portion of peripheral vision in which color changes and motion (flashing) are detected.

The push buttons to respond to and control the EM features on the AAR screens exceed the normal reach envelope, but reside within the extended reach envelope and are well below shoulder height for even small operators. Given that physical interactions with the AAR screens, as related to EM, will be infrequent while the train is in motion, this is acceptable.

9.2.2.2 **CDU Screens**

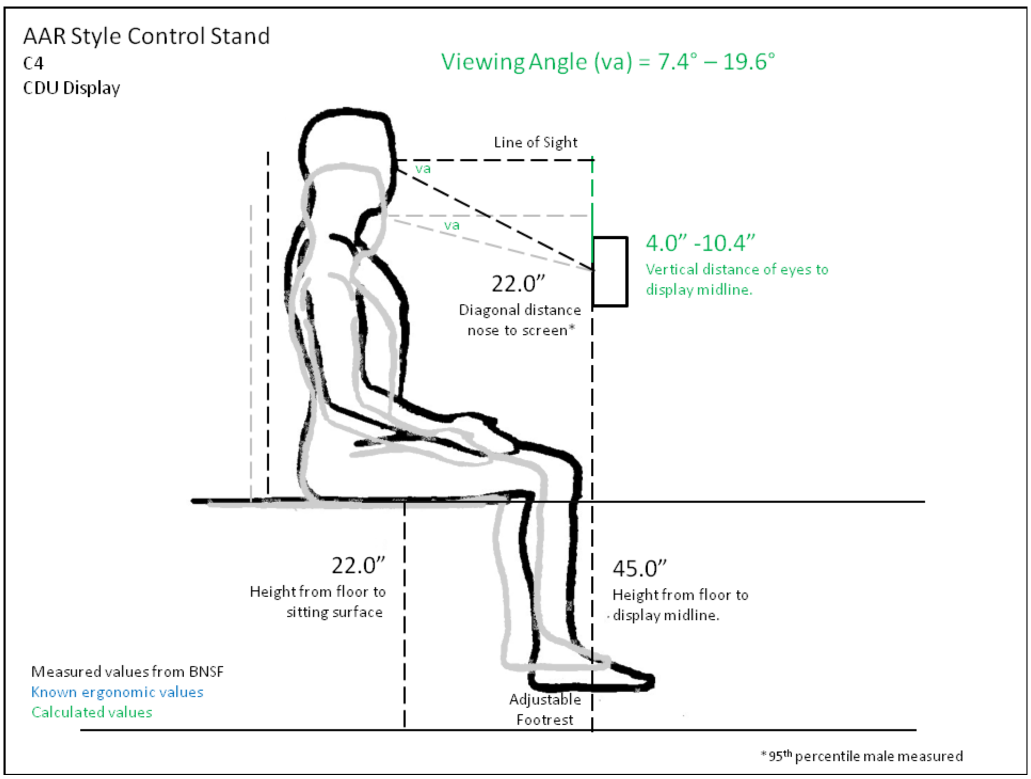

FIGURE 1: AAR STYLE CONTROL STAND, C4 CDU DISPLAY - VIEWING ANGLE

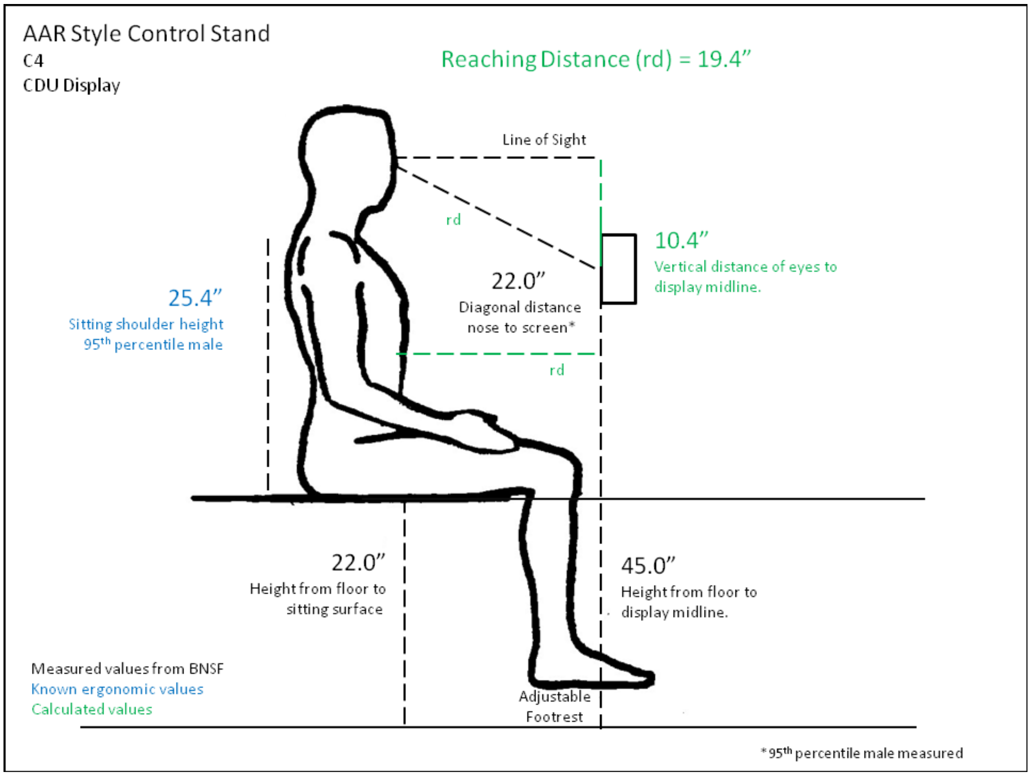

FIGURE 1: AAR STYLE CONTROL STAND, C4, CDU DISPLAY - REACHING DISTANCE

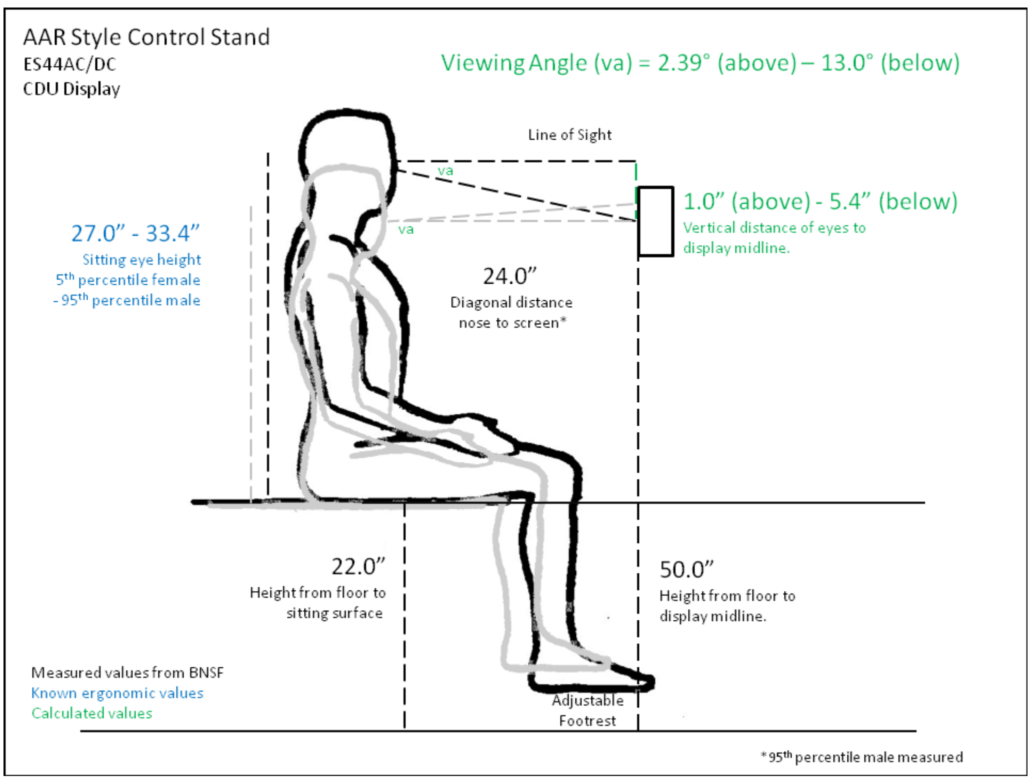

FIGURE 1: AAR STYLE CONTROL STAND, ES44AC/DC CDU DISPLAY - VIEWING ANGLE

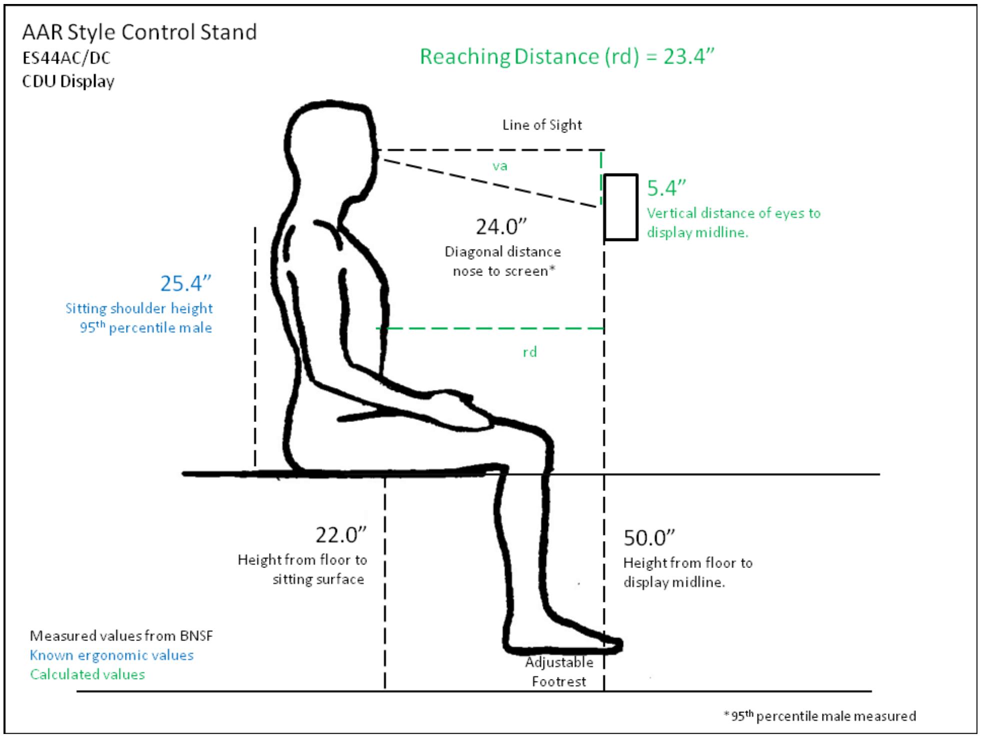

FIGURE 1: AAR STYLE CONTROL STAND, ES44AC/DC CDU DISPLAY - REACHING DISTANCE

For implementation in which the EM is integrated into the PTC display, the CDU location is less than ideal, given its position to the side of the operator (discussed below).

The midline height the screens are 23.0 and 28.0 inches above the sitting surface, leading to viewing angles ranging from 19.6° below to 2.39° above the line of sight. For most operators, the viewing angle is within acceptable levels of vertical eye rotation to bring the screen into foveal view.

While the push buttons to respond to and control the EM features on the CDU exceed the normal reach envelope, they reside within the extended reach envelope. However, the controls will be at or above shoulder height for most operators. This could lead to arm fatigue, though physical interactions with the controls are infrequent.

However, with the CDU located to the side of the operator, it is likely on the edge of the area of peripheral vision in which color changes are detectable. Though the screen remains within the portion of peripheral view in which motion is detected, in this implementation the EM components do not flash to increase the saliency of the elements. In other words, it is less likely that the operator will detect increases in saliency of the CDU EM prompts from cyan to yellow while looking out the front windshield.

9.3 Conclusions

With the exceptions of the concerns noted above, the placement of the AAR screens and CDU are acceptable from an ergonomic perspective with respect to the addition of the EM features.

However, for the AAR style control stand with the CDU placed to the side of the engineer, the engineer will be more likely to notice, and therefore respond to, EM prompts that are presented on the AAR screen, as opposed to those that are presented on the CDU.