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BNSF Energy Management
Human Factors Evaluation
PTC CDU Integrated Screen Configuration

Final Report

April 14, 2016

Enclosed Document Revision Histories

Heuristic Evaluation & Cognitive Walkthrough

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Cognitive Workload Assessment of Crew Interactions with EM

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Ergonomic Analysis of AAR Screen & CDU Placement

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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; 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 PTC CDU 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.

In this implementation of EM, the interface consists of information displays and interaction components that are integrated into the existing PTC screen designed by GE Transportation and WABTEC. These include plan speeds integrate into the existing track line map, visual prompts and messages to the operator; audible tones; and push-button controls. In this implementation, EM cannot be run in standalone mode.

1.2 Onboard Display Hardware

The PTC CDU onboard display consists of a color screen display with push-button controls arranged in a horizontal row 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.

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 (TO) (the EM feature),
- To initiate and disengage Auto Control.

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

- Adjust throttle to enter / exit Auto Control,
- To modify air brakes when prompted by EM

(Note that this implementation has the ability to control the air brakes, but BNSF has no plans to pursue that functionality at the moment; air brakes will remain under the control of the engineer).

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 PTC CDU display located within the confines of the locomotive. An analysis was undertaken to examine the placement of the CDU 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 CDU and the AAR display.

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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BNSF Energy Management

Human Factors Evaluation

PTC CDU Integrated Screen Configuration

Heuristic Evaluation

&

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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)
  - *WRE White Paper Energy Management HMI Update Revision 2.0, WABTEC Railway Electronics*
- discussions with Stephen Muncy, Director Operating Practices-Fuel Conservation/PTC, BNSF
- previous experience with the PTC CDU and the proposed integration of the EM features[1]

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.[2]

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

[1] Dr. Johnson performed the final HFA of the WABTEC PTC HMI, the report for which was released to Union Pacific in November 2013.

[2] "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.

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 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 human factors concerns associated with the EM components that are integrated into the AAR screen – this reviewer finds no issues that will overtly compromise the safety of the train, crew, passengers, other railroad employees or civilians, or other equipment.

However, this reviewer questions the wisdom of integrating EM into PTC displays.

The goal of PTC is to prevent rail accidents caused by the failure of the train crew to adhere to movement and speed restrictions. One of the objectives of the PTC HMI design was to minimize and discourage crew interactions with PTC during train movements. Operators who run conservatively incur very few warnings that would even necessitate visual interaction with the display. Physical interactions were limited to responses to prompts that, if not responded to, would necessitate stopping the train, and where other actions were permitted, these actions were deemed important to safe train handling (e.g. reviewing mandatory directives or reviewing changes to the train consist).

Adding EM features to this display encourages crew interactions with PTC during train movements beyond those that are necessary for safe train handling, circumventing the above goal. Further, given the above restrictions, the PTC CDU was allowed to be placed in locations that are not always ideal to facilitate interaction during train movement, and is in some cases located to the side of the engineer.

However, should this implementation move forward, the following usability issues should be addressed.

4.1 Major Human Factors Concerns

The following issue may impact the efficiency of train operations by increasing the number of avoidable enforcements applied by the system, either as PTC Penalty brake applications or as EM forced idles.

4.1.1 Yellow Overlay Messages

Do not use yellow for EM messages, as these are not "safety related".

The EM system uses two message boxes to convey information to the engineer. The colors used for these displays as defined by WABTEC (see sections 2.4.1 through 2.4.3 of the *WRE White Paper Energy Management HMI Update)* are:

- gray for information messages,
- cyan for those requiring action by the crew, and
- yellow to alert the crew to actions needed for safety compliance.

In practice, from a review of the messages provided, yellow is used when actions are required on the part of the crew to transition between Manual and Auto Control modes. See Figure 1: Yellow EM Overlay Messages for a list of EM messages presented with a yellow background and an example of the yellow message area in use.

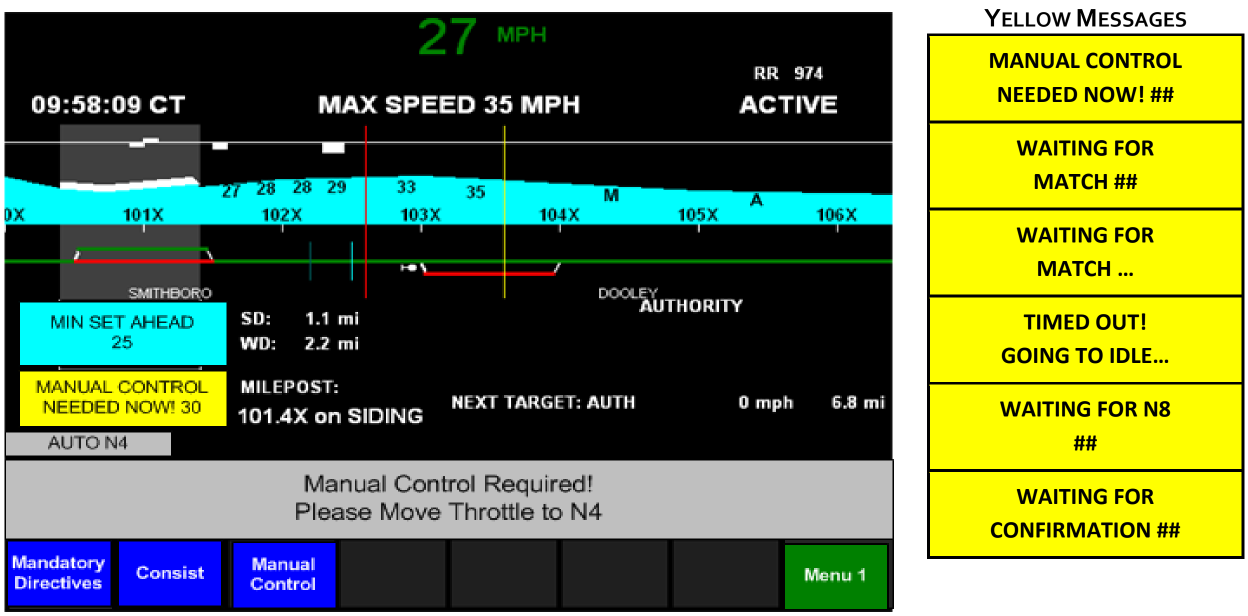

FIGURE 1: YELLOW EM OVERLAY MESSAGES

The PTC system has clearly established the use of yellow outside of the Track Line Map to indicate required actions that are related to safety and that, if not taken, will result in a Penalty Brake Application. Yellow PTC banners indicate that the system will apply a penalty brake within the time indicated. The only escalation beyond this graphical element, which is signified by a red banner, results in a penalty brake application.

The Overlay Message Boxes should not use yellow to indicate actions that, if not taken, will result in a forced idle. Though both are "penalties" applied by the system, the end results and implications to operator train handling are dramatically different.

Presenting EM messages with a yellow background over emphasizes the consequences of not taking EM related actions and dilutes the message conveyed by the yellow PTC banner – that a penalty brake implication is imminent.

The end result of displaying EM message with a yellow background will be a slowdown in the cognitive processing of the both the EM and PTC messages.

A different color or a different coding mechanism must be used to convey the urgency of EM related actions. For example, consider the following alternative for lower and higher priority EM messages:

FIGURE 2: ALTERNATIVE IMPLEMENTATION FOR LOWER AND HIGHER PRIOR EM MESSAGES

4.2 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 a minor disruption of situation awareness. These issues are unlikely to impact safety and are unlikely to lead to avoidable enforcement. However, correcting these issues will reduce cognitive workload and potential confusion on the part of the user and will minimize any potential disruptions to the crews' ability to maintain situation awareness.

4.2.1 Lack of an Indication for Upcoming Need for Air Brakes

Provide a more explicit indication of an upcoming need for air brakes.

In the AAR implementation there is a visual indication of an upcoming need for airbrakes. There is not a similar indication in this implementation.

However, it is not apparent whether such an indication is necessary and beneficial to the user in this implementation.

This issue is to be reviewed in detail during observations of the system.

4.2.2 Low Saliency of Upcoming Manual Control Zone

Increase the salience of the upcoming Manual Control Zone indication.

In the AAR implementation, upcoming Manual Control Zones are depicted with gray backgrounds on the Rolling Map, which is very salient. In this implementation, the corresponding indication is an M placed in line with the Plan Speeds. The saliency of this element is very low. While the Overlay Message Boxes will also alert the user to upcoming manual control zones, consider increasing the saliency of this indictor, such as presenting it in a different color, or increasing the size of the font, or presenting a border around the M.

Note that this issue ties in with the issues discussed in 4.3.1 Visual Density Associated with Plan Speeds. Alternative implementation examples are presented in Figure 6: Proposed Changes for EM Plan Speeds that are in line with the recommendations to resolve the issue discussed in that section. The image depicted below represents an alternative implementation of the existing design.

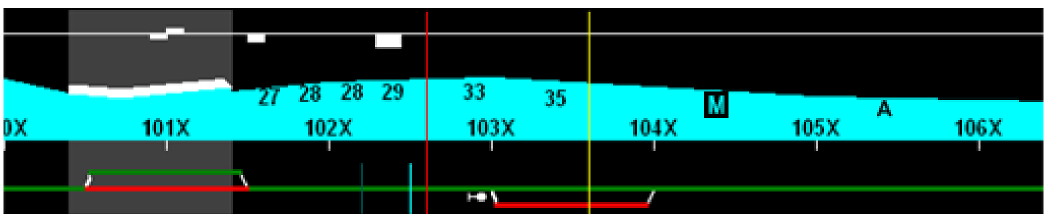

FIGURE 3: YELLOW EM OVERLAY MESSAGES

It should be noted that plan speeds have the capability of flashing, which is not currently utilized by BNSF. This is a circumstance under which flashing the plan speed would be acceptable from a human factors perspective, if no other acceptable alternative can be implemented.

There is not a similar need to make the Auto Control indicator salient, as there is no EM system penalty to not engaging in Auto Control when it is available.

4.2.3 Unnecessary Welcome Screen

Eliminate the Welcome Screen.

The engineer is able to initiate TO and start a trip while the train is moving, which has the potential to divert the engineer's attention away from the track ahead. For that reason alone it is imperative to streamline the process to initiate TO.

The Welcome screen below is presented after the engineer accepts a trip, to confirm that TO and the trip are active. However, this screen provides no real value to the user aside from confirming that TO and the trip have been initiated and providing a means to end the trip. Further, though it is assumed that any message from PTC would cause this screen to be removed, this screen still competes with PTC for display time.

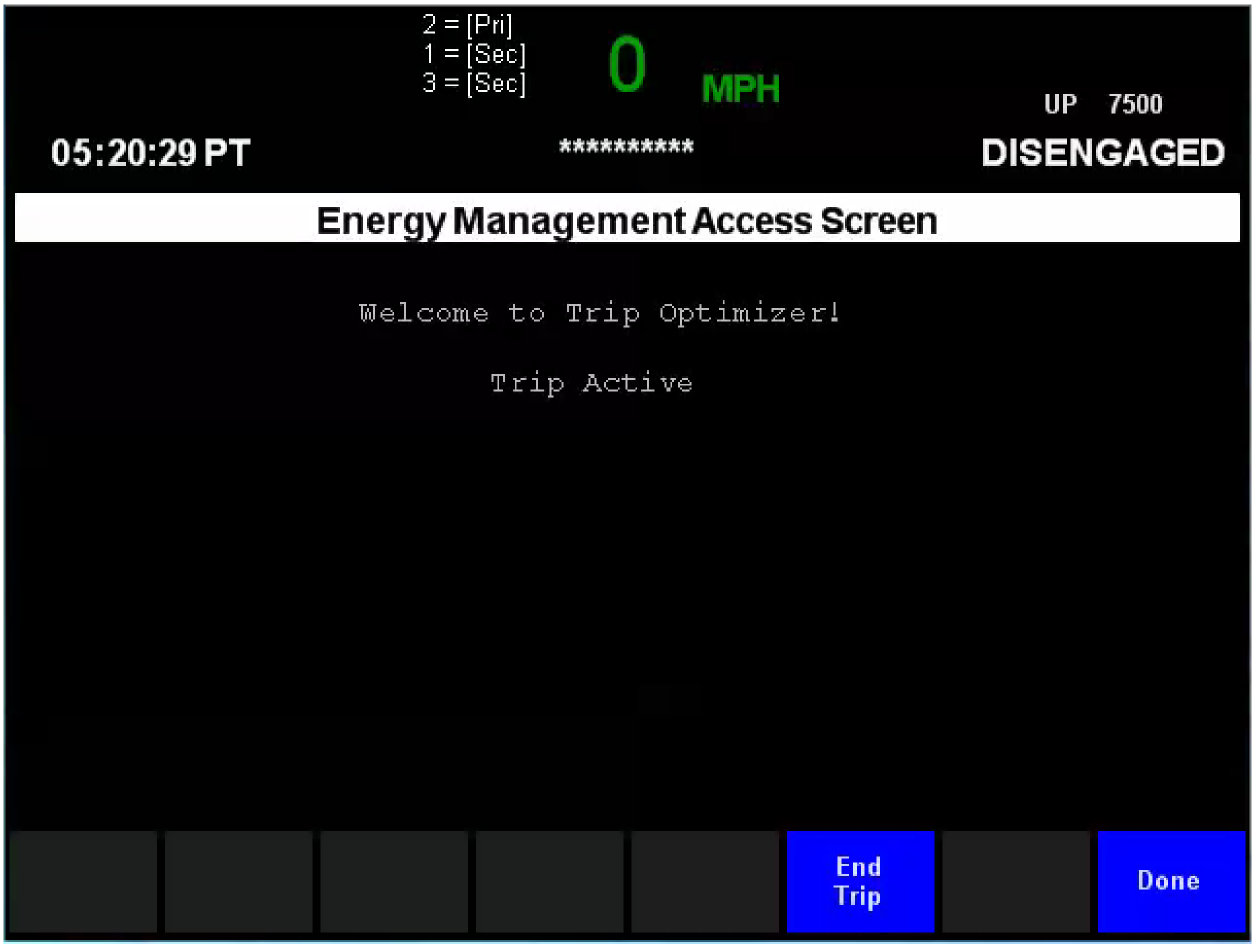

FIGURE 4: WELCOME SCREEN

Eliminate this screen and move the confirmation message to a banner message or present it via the recommended persistent TO indicator (see 4.3.2 Lack of Explicit EM Active Indication). The means to end the trip should be moved to another screen or implemented as a button press directly accessible from the PTC menu.

4.3 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.

4.3.1 Visual Density Associated with Plan Speeds

Redesign the display to further separate Plan Speeds from mileposts.

Eliminate redundant Plan Speeds.

While EM is in Auto Control, the PTC track line elevation graphic displays the upcoming EM plan speeds as depicted below:

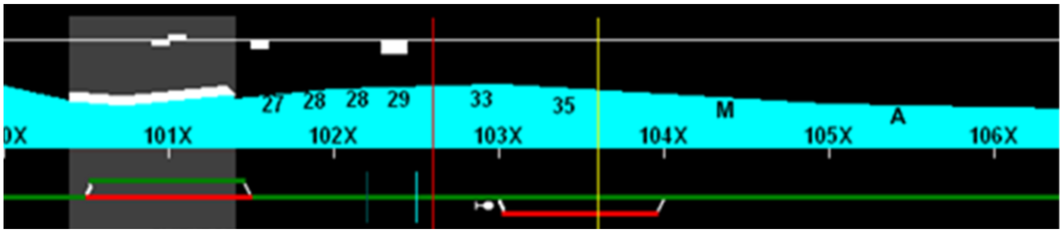

FIGURE 5: EM PLAN SPEEDS DISPLAY

As implemented, the plan speeds 1) increase the visual density of this part of the interface, particularly when the plan speeds include redundant speeds; and 2) are hard to differentiate from the mileposts because they are tightly spaced with the mileposts and use the same font type and color as mileposts.

If possible, consider placing the plan speeds above the track elevation so that the train appears to be "driving through" the plan speed. This dramatically reduces the visual clutter and visually ties the plan speed to the train's forward movement.

Consider also restricting plan speed indicators to only those that add unique value. The above example fails to meet this criterion, as a second value of 28 immediately follows the first 28, providing no unique value.

Both recommendations are depicted below:

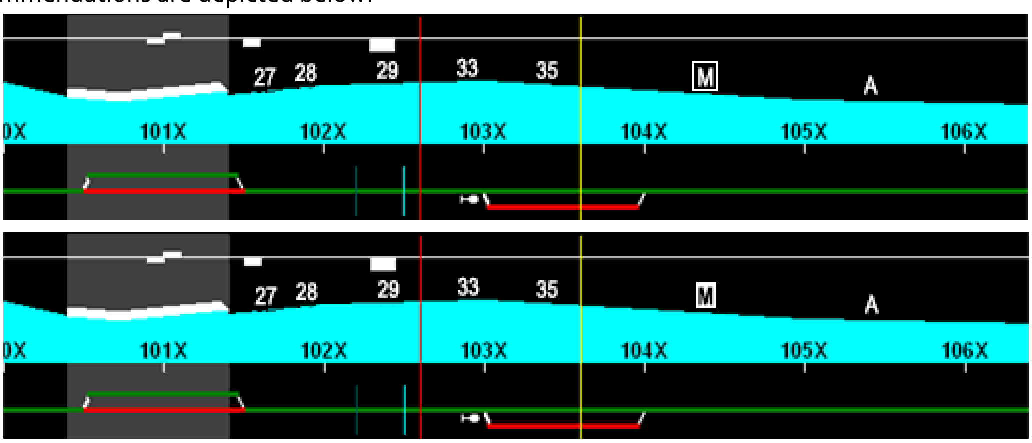

FIGURE 6: PROPOSED CHANGES FOR EM PLAN SPEEDS

Note that the use of white for the plan speeds in the above depiction further contributes to the visual association of the train and the plan train speeds, and the depiction of the Manual Control Zone indictor is in line with recommendations from section 4.2.2 Low Saliency of Upcoming Manual Control Zone.

4.3.2 Lack of Explicit EM Active Indication

Make the EM Control Indictor a persistent element to indicate EM active state.

In the AAR implementation, the Rolling Map is present only when EM is active, which serves as a very clear indication of the system status (e.g. EM active versus not active). Because the rolling track line map is already an integral part of the PTC HMI, its presence does not provide the same clear system status indication. There is no other clear indication that EM is active, as the EM Control Indicator, Overlay Message Boxes, EM Banner, and EM-associated push button are not persistent elements.

Consider making the EM Control Indictor a persistent element to indicate EM active state. In cases where it is not already on screen, consider adding an "EM Enabled" message to ensure it is always present.

4.3.3 Advisory Text Banner

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

Simplify text where possible.

Refer to control modes consistently.

The BNSF implementation of the EM Banner uses only the Advisory Text Banner as described in sections 2.4.1 through 2.4.3 of the *WRE White Paper Energy Management HMI Update* instead of the fully featured, segmented banner that includes a countdown timer, free form text, and multiple data groups. There are no issues with the design of the banner when it is used to display only text.

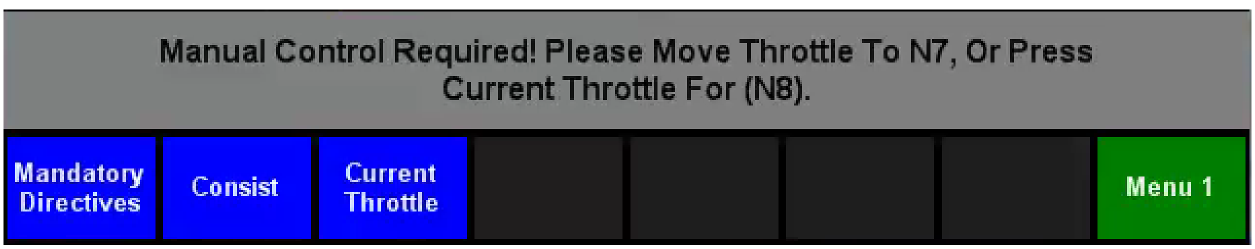

FIGURE 7: EM ADVISORY TEXT BANNER

However, there are several issues with the way that text is presented within the banner.

First, there is a great deal of evidence that reading prose is easier when capitalization is used conventionally to start sentences and to indicate proper nouns and acronyms[3]. In other words, use sentence style capitalization for sentences, and book title capitalization for button labels within that text. This will speed processing of the message and will make references to button labels more clear.

Note that the banner text refers to the control modes as "Manual", "Manual Operation", "Manual Control", "Auto", "Automatic Control" and "Auto Control", while the buttons always refer to these as "Manual Control" and "Auto Control". Banner text should always be consistent with the button labels; always use "Auto Control" and "Manual Control" to refer to these modes.

Use line breaks to separate alternative instructions, where possible, for improved readability.

TABLE 2 – BANNER MESSAGES

Text ID	Message Text	Revised Message Text

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

Text ID	Message Text	Revised Message Text
1	Auto Control Not Available: Location Mismatch With PTC.	Auto control not available: location mismatch with PTC.
2	Auto Control Not Available: Data Synchronization Error With PTC.	Auto control not available: data synchronization error with PTC.
3	Auto Control Not Available: Speed Mismatch With PTC.	Auto control not available: speed mismatch with PTC.
4	Place Throttle In N8 Before Timeout To Continue Automatic Control, Or Press Manual Control To Return To Manual Operation.	Place throttle in N8 before timeout to continue to auto control, or press Manual Control to return to manual control.
5	Continue Automatic Control?	Continue to auto control?
6	For Manual Control: Move Throttle To Nx, Or Press Current Throttle For (Ny).	For manual control, move throttle to Nx, or press Current Throttle for Ny.
7	For Manual Control: Move Throttle To Nx.	For manual control, move throttle to Nx.
8	Manual Control Required! Please Move Throttle To Nx, Or Press Current Throttle For (Ny).	Manual control required! Move throttle to Nx, or press Current Throttle for Ny.
9	Manual Control Required! Please Move Throttle To Nx.	Manual control required! Move throttle to Nx.
10	For Manual Control: Move Dynamic Brake Handle To Bx Or Greater	For manual control, move dynamic brake handle to Bx or greater.
11	For Manual Control: Move Dynamic Brake Handle To Bx Or Greater, Or Press Current Throttle For Idle.	For manual control, move dynamic brake handle to Bx or greater, or press Current Throttle for idle.
12	For Manual Control: Move Dynamic Brake Handle To Bx Or Greater, Or Press Current Dyn Brake For (By).	For manual control, move dynamic brake handle to Bx or greater, or press Current Dyn Brake for By.
13	For Manual Control: Move Dynamic Brake Handle To B8.	For manual control, move dynamic brake handle To B8.
14	For Manual Control: Move Dynamic Brake Handle To B8, Or Press Current Throttle For Idle.	For manual control, move dynamic brake handle To B8, or press Current Throttle for idle.
15	For Manual Control: Move Dynamic Brake Handle To B8, Or Press Current Dyn Brake For (By).	For manual control, move dynamic brake handle To B8, or press Current Dyn Brake for By.
16	Manual Control Required! Please Move Dynamic Brake Handle To Bx Or Greater.	Manual control required! Move dynamic brake handle to Bx or greater.
17	Manual Control Required! Please Move Dynamic Brake Handle To Bx Or Greater, Or Press Current Throttle For Idle.	Manual control required! Move dynamic brake handle to Bx or greater, or press Current Throttle for idle.
18	Manual Control Required! Please Move Dynamic Brake Handle To Bx Or Greater, Or Press Current Dyn Brake For (By).	Manual control required! Move dynamic brake handle to Bx or greater, or press Current Dyn Brake for By.
19	Manual Control Required! Please Move Dynamic Brake Handle To B8.	Manual control required! Move dynamic brake handle to B8.
20	Manual Control Required! Please Move Dynamic Brake Handle To B8, Or Press Current Throttle For Idle.	Manual control required! Move dynamic brake handle to B8, or press Current Throttle for idle.
21	Manual Control Required! Please Move Dynamic Brake Handle To B8, Or Press Current Dyn Brake for (By).	Manual control required! Move dynamic brake handle to B8, Or press Current Dyn Brake for By.
22	Transfer To Auto Timed Out! To Recover, Please Put Throttle In Idle.	Transfer to auto control timed out! To recover, put throttle in idle.
23	Transfer To Manual Timed Out! To Recover, Please Put Throttle In Idle.	Transfer to manual control timed out! To recover, put throttle in idle.
24	Please Wait…	Timed out! Going to idle. Please wait…
25	Trip Optimizer System Error! Locomotive In Manual Operation.	Trip Optimizer error! Locomotive in manual control.
27	Trip Optimizer System Available. Use Energy Management Screen To Complete Trip Optimizer Initialization.	Trip Optimizer available. Use Energy Management Screen to complete Trip Optimizer initialization.

Text ID	Message Text	Revised Message Text
28	Throttle Must Be In Idle To Exit Trip Optimizer.	Throttle must be in idle to exit Trip Optimizer.
29	Train Is Operating In Distributed Power Independent Mode. Please Press Confirm To Continue.	Train Is operating In distributed power independent mode. Press Confirm to continue.

Note: parentheses that surround some characters are intended to denote variables, and do not appear in the text..

4.3.4 Ambiguous Button Labels

In the features acceptance screen, the engineer may accept the trip information and enable TO or may reject the trip and exit TO. However, the button to reject the trip is "Done". Though instructions are present on the screen, regarding this button, "Done" is too ambiguous. This button should be "Reject" to clarify its action.

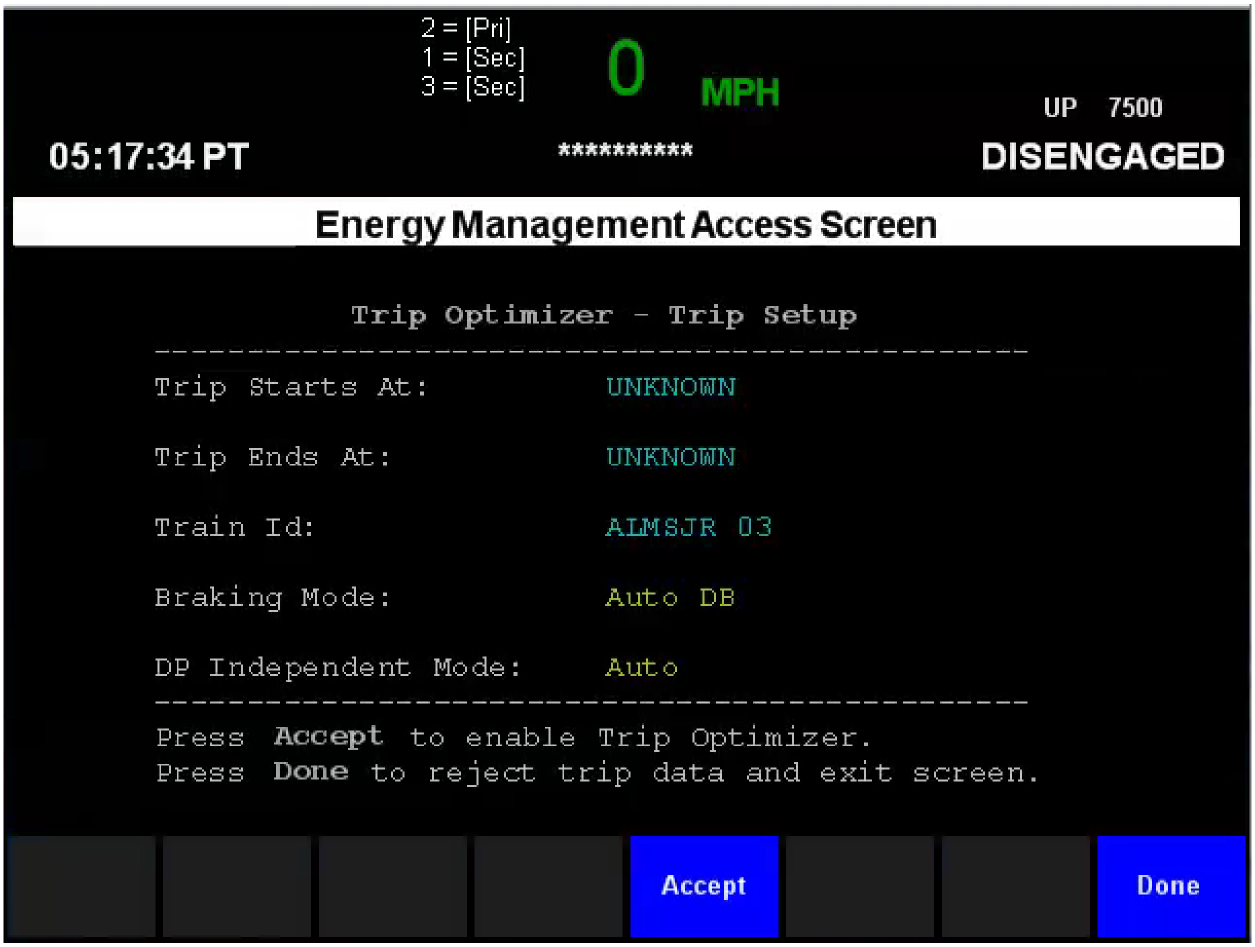

FIGURE 8: FEATURES ACCEPTANCE SCREEN

All button labels should be evaluated for clarity of action.

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Human Factors Evaluation

PTC CDU Integrated 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.

In this implementation of EM, the UI consists of information displays and interaction components that are integrated into the PTC CDU user interface designed by WABTEC. These components include Plan Speeds and Control Zone Indicators on the Trackline Map, color-coded text prompts, with accompanying descriptive messages, an added auditory tone, and added soft key push-button controls to interact with the displays.

EM can only be run in combination with PTC enforcement in this implementation.

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 when needed:

- To initiate and end a trip,
- To initiate and disengage Auto Control mode.

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

- Adjust throttle to enter / exit Auto Control,
- To modify air brakes when prompted (EM has no connection to the air brakes).

User interactions with EM have the potential to 1) cause cognitive workload in addition to that which is already required on the part of the crew to safely operate the train; and 2) 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 the Engineer by the use of and interactions with EM 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 concern 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, which impact the crew's ability 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 (e.g. 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 on the use of EM as an advisory and control system, and the potential of interactions with the system to increase the cognitive workload of the engineer and to divert attention from monitoring track ahead of the train. This analysis does not examine actions that are external to the EM interface, such as recording on paper instances of non-use.

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.

Use of EM 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.

6 Train Operating Scenarios

The cognitive workload imposed on the crew for any task accomplished by interacting with the EM system 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 and maintaining awareness of the track ahead – they do not occur simultaneously with these tasks. Moreover, they have no time-constraints on completion; crews may take as much time as needed without affecting train

[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.

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.

Further, as noted in the Heuristic Evaluation & Cognitive Walkthrough (see section 4 Human Factors Concerns Human Factors Concerns), an original goal of the PTC CDU HMI was to reduce crew interactions as much as feasible while the train was in motion. Given this, the PTC CDU was permitted to be placed in non-optimal locations, including to the side of the engineer. Thus, any interactions with the CDU would necessitate the engineer momentarily diverting attention from the track ahead. This was deemed acceptable for PTC interactions, which ensure safe train movements.

This reviewer questions the wisdom of integrating EM into the PTC display, as EM interactions are not required to ensure safe train movements. A preferred implementation would integrated EM into screens that are already within the line of sight for the track ahead.

6.1 Initiating Trip Optimizer

In the PTC CDU implementation of EM all information that is required by EM to initiate the feature is acquired during the PTC initiation process. Therefore, there is no separate task to initiate trip optimizer.

6.2 Starting a Trip

The engineer is able to start the EM trip both while the train is stopped and while it is at non-zero speeds. To do so, the engineer presses the Menu 1 button in the PTC display, which accesses the auxiliary menu, and presses Energy Mgmt from that menu.

This presents an Energy Management Access Screen, which displays trip information, include starting and ending points, the train ID, and the braking and DP independent modes.

The user can either accept the information, via the Accept key, which starts the trip and displays the Welcome screen, or he may reject the trip by selecting the "Done" key, which exits the EM screen.

Once the Welcome screen is displayed, the engineer can either end the trip, via an "End Trip" key or exit back to the Main screen, with EM enabled, via another "Done" key.

Navigating these screens while the train is stopped can have no impact on the ability of the crew to maintain situation awareness.

To navigate these screens while the train is moving currently requires 4 button presses: Menu 1, Energy Mgmt, Accept, Done, and the navigation of 2 screens. The Heuristic Evaluation & Cognitive Walkthrough includes recommendations to streamline this process by eliminating the Welcome screen and replacing it with a banner message or a persistent EM indication on the Main Screen.

Should these steps be taken, only the act of reviewing information on the Energy Management Access Screen would divert the engineer's attention from the track ahead. Given that Trip Information should already be known to the engineer, validating the information should not increase the cognitive workload of the operator and any diversion from the track ahead will be minimal.

Moreover, should a PTC banner need to be displayed while the EM Access Screen is present, the system will snap back to the Main screen of the PTC to allow the operator to review the PTC safety information.

Should other circumstances (unrelated to PTC) arise that require the attention of the operator, there is no system penalty involved with not responding (accepting or rejecting the trip). The system will remain on the EM Access Screen until the operator responds, or until a PTC banner is displayed. It is also reasonable to assume that the engineer will not attempt to start a trip when his attention is required by other tasks and/or systems.

6.3 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.

6.3.1 Awareness of System State

During Train Operation, the engineer must be aware of the current EM system state, which primarily involves determining or remembering whether EM is active and which is the active control mode.

The active control mode is readily apparent when in Auto Control Mode, as the Plan Speeds and Control Zone Indicators appear on the Trackline Map.

However, the status is less obvious when a trip is in progress and the system is in Manual Control. This should not be an issue, given that there are no actions required on the part of the crew while in Manual Control. However, the lack of an indication in this mode may lead to momentary confusion on the part of the operator, as to whether or not EM is active. The Heuristics Evaluation & Cognitive Walkthrough provides recommendations to include a persistent indicator of the EM trip status on the Main Screen (see section 4.3.2 Lack of Explicit EM Active Indication).

6.3.2 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 unaffected by the presence of the EM system.

The only exception may be momentary confusion as to the active or inactive status of EM, as there are no persistent indicators that EM is active when in Manual Control (as noted above).

6.3.3 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 the system will revert to Manual Control once the operator recovers from the Forced Idle (see 6.3.5 Responding to Forced Idle States).

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 6.3.5 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.

6.3.4 **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 and the need to disengage Auto Control. Other prompts involve informational messages 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, which will speed processing of these messages.

However, as noted in the Heuristic Evaluation & Cognitive Walkthrough, the use of yellow to increase the saliency of EM prompts concerns this reviewer. Yellow is already used by PTC to indicate an impending penalty brake. Using yellow to indicate an impending forced idle overemphasizes the consequences of not responding to EM prompts, which will also have the effect of reducing the clarity of the PTC prompts. This reviewer predicts that a slowdown in processing of PTC messages will result. See section 4.1.1 Yellow Overlay Messages for greater discussion of the issue and recommendations to modify the interface to eliminate this issue.

6.3.4.1 **Disengaging Auto Control**

Aside from the issues noted above (the use of yellow in EM), there are no cognitive workload concerns with disengaging Auto Control.

[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..

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 Overlay Message Prompts, and in the case of Manual Control Zones, by a graphical indicator on the Trackline 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 6.3.5 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 6.3.4 Train Operation in Auto Control Mode / Responding to EM Initiated Prompts) and 1-2 button presses.

Disengaging Auto Control should not affect the cognitive workload of the operator.

6.3.4.2 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 6.3.5 Responding to Forced Idle States).

These prompts do not use yellow as a background, and do not share the concern noted above. Observing and responding to these prompts should not impact the cognitive workload of the operator.

6.3.4.3 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 nature.

6.3.5 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.

6.3.6 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 6.3.4.1 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.

6.4 **Ending a Trip**

The Engineer may choose to end the trip. Operationally, this should be done only at the end of the trip. Ending the trip currently requires pressing Menu 1 to access the Auxiliary menu, pressing Energy Mgmt to access the Welcome screen, pressing End Trip and confirming the desire to end the trip.

Doing so can only be accomplished from Manual Control mode, but can be done while the train is in motion.

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, and should a PTC banner need to be displayed, the system will snap back to the Main Screen.

However, this reviewer questions whether the ability to End the trip should only be available while the train is stopped, and does not see the advantage in allowing the engineer to end the trip while the train is moving.

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). Further, there are no time- or attention-intensive tasks associated with EM.

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 otherwise require the attention of the engineer.

Moreover, while the use of yellow in the EM system can be modified to eliminate concerns regarding the slowdown of processing of PTC messages, this reviewer questions the wisdom of integrating EM into the PTC display. The goal of PTC is to prevent rail accidents caused by the failure of the train crew to adhere to movement and speed restrictions. One of the objectives of the PTC HMI design was to minimize and discourage crew interactions with PTC during train movements. Adding EM features to this display encourages crew interactions with PTC during train movements beyond those that are necessary for safe train handling, circumventing the that goal.

Further, given the above, the PTC CDU was permitted to be placed in non optimal locations, including to the side of the engineer. Thus, any interactions with the CDU could necessitate the engineer diverting attention from the track ahead. These fleeting diversions were deemed acceptable for PTC interactions, which ensure safe train movements. This is less acceptable for EM, as these interactions are not required to ensure safe train movements. EM should ideally be integrated into screens that are already within the line of sight for the track ahead.

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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 that will be integrated into the WABTEC Positive Train Control (PTC) Cab Display Unit (CDU).

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.

The UI consists of information displays and interaction components that are integrated into PTC CDU HMI as designed by GE Transportation and WABTEC. These include: Plan Speeds and Control Zone indicators (both Auto and Manual) on the Track Line Map; an EM Control Indicator; 2 overlay message areas; a message banner that provides additional information, and EM soft button controls.

This Human Factors Evaluation (HFE) focuses only on EM; the remaining components of the PTC HMI are outside the scope of the project. As such, the following responses relate to the design of the EM UI, though aspects of the workstation design and hardware are discussed, as appropriate.

However, it must be note that this reviewer questions the decision to integrate the EM features into the PTC CDU HMI. As noted in the Heuristic Evaluation & Cognitive Walkthrough, one objective of the PTC HMI design was to minimize and discourage crew interactions with PTC during train movements. Physical interactions were limited to responses to prompts that, if not responded to, would necessitate stopping the train, and where other actions were permitted, these actions were deemed important to safe train handling.

Contrary to this goal, the EM feature encourage crew interactions with PTC during train movements beyond those that are necessary for safe train handling, circumventing the above.

(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 a trip,
- To initiate and disengage Auto Control mode.

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

- Adjust throttle to enter / exit Auto Control,
- 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, due to lack of response from the engineer to displayed prompts.
- When displaying the EM Access Feature or Welcome screen, should PTC require that a banner be displayed, the system will automatically exit these screens and return to the Main Screen.

To place the system in Auto Control, the engineer selects the Auto Control push-button and places the throttle in N8, as prompted. If the system successfully transitions into Auto Control mode, the Plan Speeds appear on the Trackline Map. If the engineer fails to place the throttle in N8, the system will enter a Forced Idle, 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 engineer based on contextual cues. Messages in the prompt and banner area also appear to indicate the system status. When the user recovers from the Forced Idle, the system remains in Manual 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 direct EM related action is required on the part of the engineer (direct meaning physical interaction with the system) 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.

During Auto Control EM may require the engineer to modify the air brakes. In such cases, the engineer must observe prompts and messages provided by EM and modify the brakes accordingly. Prompts appear in the overlay message area and a banner message will appear to alert the engineer to the need, provided that PTC is not already displaying a banner message. Should the engineer fail to respond, the system enters a Forced Idle. This implementation does not provide a graphical indication on the Trackline

Map of the upcoming need for air brakes. Such an indication should be considered (see section 4.2.1 Lack of an Indication for Upcoming Need for Air Brakes).

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 Trackline Map when the train is 2 miles from the zone and prompts appear to alert the engineer for the need to shift control modes. It should be noted that the H*euristic Evaluation & Cognitive Walkthrough* provides recommendations to increase the saliency of the Manual Control Zone indicator on the Trackline map (see section 4.2.2 Low Saliency of Upcoming Manual Control Zone). Should the engineer fail to respond, the system will enter a 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 and to adjust the throttle position to smoothly transition between control modes, as described above.

When the air brakes are required, the system alerts the engineer with prompts in the overlay message area, and provided no PTC banner messages are displayed, will also present a more detailed message in the banner area. The overlay prompts increase in saliency as the need for the air brakes increases – changing from gray to cyan, along with the addition of an alert tone, where appropriate. Should the engineer fail to respond, EM will enter Forced Idle.

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 fail to transition to Auto Control, enter a Forced Idle, and return to Manual Control after the operator recovers from the Forced Idle.

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 a banner message provides instructions to change the throttle position (when not overwritten by PTC messages). 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 Forced Idle.

(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. Prompts clearly convey the action required on the part of the engineer and are presented with graphical components (background colors) that convey the urgency of the prompt. However, as noted in the *Heuristic Evaluation and Cognitive* Walkthrough, this reviewer has concerns regarding the use of yellow for EM prompts to indicate actions that must be taken to avoid a forced idle (see section 4.1.1 Yellow Overlay Messages). Yellow is already used by PTC to convey that action is required on the part of the engineer to avoid a penalty brake. Presenting EM prompts with the same background color overemphasizes the consequences of inaction and dilutes the clarity of the PTC indication, potentially reducing the processing speed of each type of prompt.

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

(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.

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

While in Auto Control, the system is intended to not impose on the cognitive workload of the crew, by presenting all information in a clear and concise format. However, as indicated in the Heuristic Evaluation and Cognitive Walkthrough (see section 4.1.1 Yellow Overlay Messages) and above, there are concerns regarding the inclusion of EM into the PTC display, and in the prominent use of yellow in the EM feature.

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.

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

(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 simple prompts. Of these, the only actions that directly manipulate EM interface are the push buttons controls to initiate Trip Optimize and to transition between control modes. The results of the button presses are consistent with user expectations, in that the button labels generally accurately convey the result of button selection. In the few instances where this is not the case, the Heuristic Evaluation and Cognitive Walkthrough provides recommendations to re-label the affected buttons (see section o Note: parentheses that surround some characters are intended to denote variables, and do not appear in the text..

Ambiguous Button Labels).

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.

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, banner messages, and graphical displays on the trackline. In either case, should the engineer not comply, the system will initiate a forced-idle.

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

Response: The intent of the EM design is to minimize the amount of time required to understand and act by increasing the saliency of prompts when action becomes more urgent, and by providing an auditory alert. However, as noted, this reviewer has expressed concerns that the use of yellow to convey that actions are required for EM will interfere with the ability of the user to process similar prompts for PTC.

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

Response: Utility tests have been conducted for the Trackline Map feature, which was based on the track line map of ETMS developed for BNSF by Wabtec. EM adds to the Trackline Map, by providing Plan speed and control zone indicators.

(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 Menu 1 button to access the auxiliary PTC menu, then to the Energy Mgmt button to access the trip information, the Welcome screen, and finally the feature itself.

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: In the PTC implementation of EM, It is not possible for the crew to introduce errors into EM. User input into the system is required only to initiate the trip.

(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 Trackline 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: Information provided by EM, beyond that provided by PTC, is limited to Plan speeds, control zone indicators, and prompts /messages, which accurately predict the system state.

(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: EM is integrated into the PTC CDU. The engineer interacts with the feature via push-button type controls that are located directly below or above the soft key representation on the screen.

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

Response: EM is integrated into the PTC CDU. Analysis of the CDU position has been conducted (see Ergonomic Analysis of AAR Screen and CDU Placement).

The exact placement of the CDU will depend on the locomotive. In some cases, the CDU will be located within the front instrument panel of the operator's console and will be within in the same pane of use as similar existing units. This placement is well within the field of view of the operator and well within the reach envelope of the seated operator, and does not obstruct the view through the cab windows.

In other cases, the CDU is placed to the front, left side of the engineer. While less ideal than that described above, the CDU will be within the reach envelope of the engineer, and within the field of view with acceptable head and eye rotation.

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

Response: As noted above, the unit is well within the reach envelope of the operator from a seated position, which is the position maintained for similar controls and displays.

(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 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 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. However, 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 also be a Forced Idle.

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

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 the first case a graphical indicator appears on the Trackline Map, which is further emphasized by the appearance of an associated prompt, presented with escalating saliency elements: changes from gray to cyan to yellow. In the second case, prompts also appear to alert the user, which again, escalate in saliency with urgency.

However, as noted previously and in the *Heuristic Evaluation and Cognitive Walkthrough*, the use of yellow prompts in EM is of concern to this reviewer and the saliency of the Manual Control Zone indicator should be increased.

(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 PTC screen does not require any structural changes to the physical workstation of the operator, beyond those necessary to incorporate the PTC CDU itself, as already analyzed by the Ergonomic Analysis of AAR Screen and CDU Placement.

Section 6: Input Devices

The input mechanism for the CDU has been proven is use. Input device consist only of eight (8) integrated buttons presented in a horizontal row either directly below or above the screen. Additional buttons along the side of the unit allow the user to control brightness and contrast for the LCD screen, but are not used for EM.

The CDU 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 user 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 placed directly above the physical buttons. The labels are displayed when the applicable button is associated with an action and are absent when the button serves no current function. Labels are written in sans serif font in title format to increase readability.

The CDU screen will be built into the front instrument panel; therefore several issues discussed in this section are not applicable, including the stability of, and unintentional movements of the device, grip surfaces and edges or corners of the device, and the handedness of the operator.

Section 7: Visual Displays

The equipment that comprises the CDU system 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 PTC CDU 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 (plan speeds, prompts regarding upcoming braking requirements and control mode transitions) 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 EM display components are integrated into the existing PTC CDU main screen. Plan speeds are integrated into the Trackline map, with push button controls located within the standard button control area of the display. Banner messages are presented in the PTC banner. The only other components are the EM indicator and overlay messages, which always appear in the same position on the screen.

(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. Moreover, it 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: Plan speeds are integrated into the Trackline Map. The only other display components are message and banner prompts, which appear in close proximity.

(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: Color is primarily used to differentiate the EM overlay message, using gray, cyan and yellow as background colors to indicate urgency of action, which is also conveyed by the text message itself. However, as noted above and in the Heuristic Evaluation & Cognitive Walk Through, the use of yellow in the EM display is a cause of concern to this reviewer.

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

Response: EM utilizes the same colors as the PTC CDU, without adding to those already used. However, as noted above and in the Heuristic Evaluation & Cognitive Walk Through, the use of yellow in the EM display is a cause of concern to this reviewer.

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

Response: Were this system a standalone display, the use of gray, cyan, and yellow to indicate urgency of action would be appropriate. However, the level of urgency conveyed by the yellow EM message is overemphasized, given that yellow is used in PTC to indicate an impending penalty brake. Yellow should not be used in the EM system.

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

Response: Information entry is not possible in EM, which utilizes only push button controls.

(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 intended to require minimal physical, visual, and cognitive interaction to avoid disrupting situation awareness on the part of the crew. The only additional actions required by the crew, once the trip has started, are to switch between control modes, which require push button activation followed by adjustments to the throttle position, and to monitor the display for EM related prompts.

However, this reviewer has concerns regarding the use of yellow to increase the saliency of EM prompts, given the use of yellow in the PTC display to signify an impending penalty brake. The use of yellow in EM overemphasizes the consequences of not responding to the EM prompts, and reduces the clarity of the PTC related prompts, which may ultimately degrade situation awareness, as the user diverts workload to determining the required course of action.

Moreover, note that, as discussed above, the *Heuristic Evaluation & Cognitive Walkthrough* provides additional recommendations to decrease processing time required for prompts and 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 are presented to the engineer. 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

PTC CDU Integrated 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.

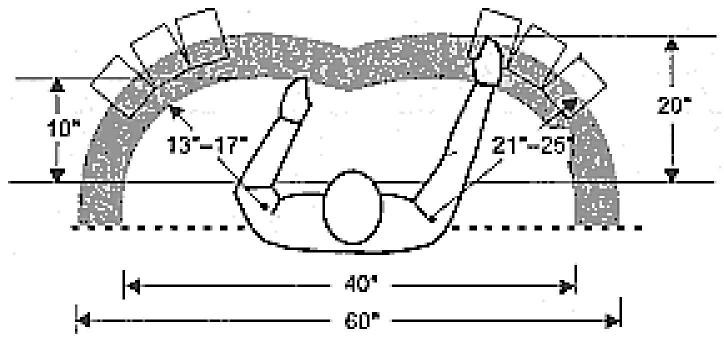

FIGURE 1: HORIZONTAL REACH ENVELOPES (ADAPTED FROM NIOSH)[6]

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.

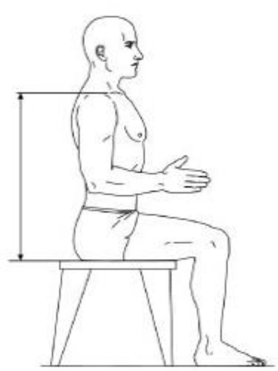

FIGURE 1: SITTING SHOULDER HEIGHT

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.

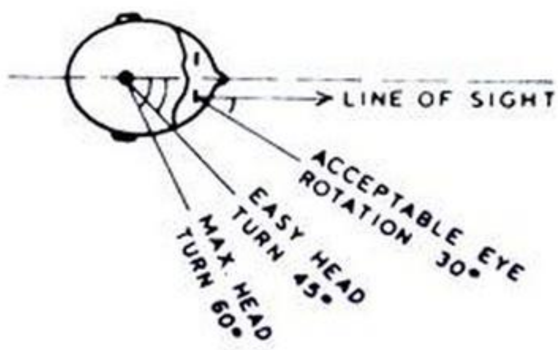

FIGURE 1: FIELD OF VIEW[8]

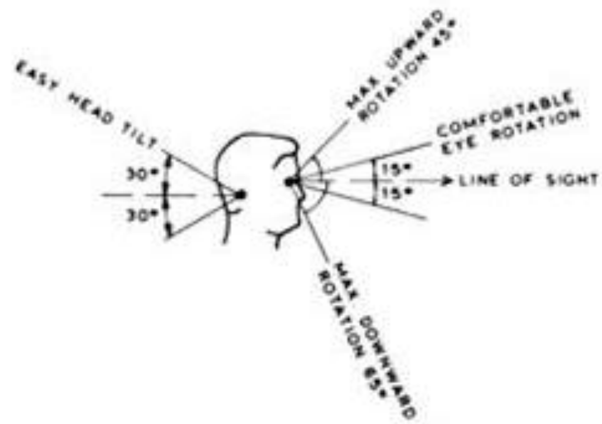

FIGURE 2: VERTICAL FIELD OF VIEW[3]

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.

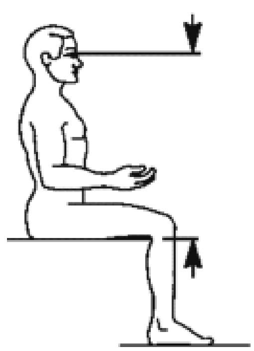

FIGURE 1: SITTING EYE HEIGHT

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 3 –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 95^{th} 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 95^{th} percentile male; extrapolated for 5^{th} percentile female.

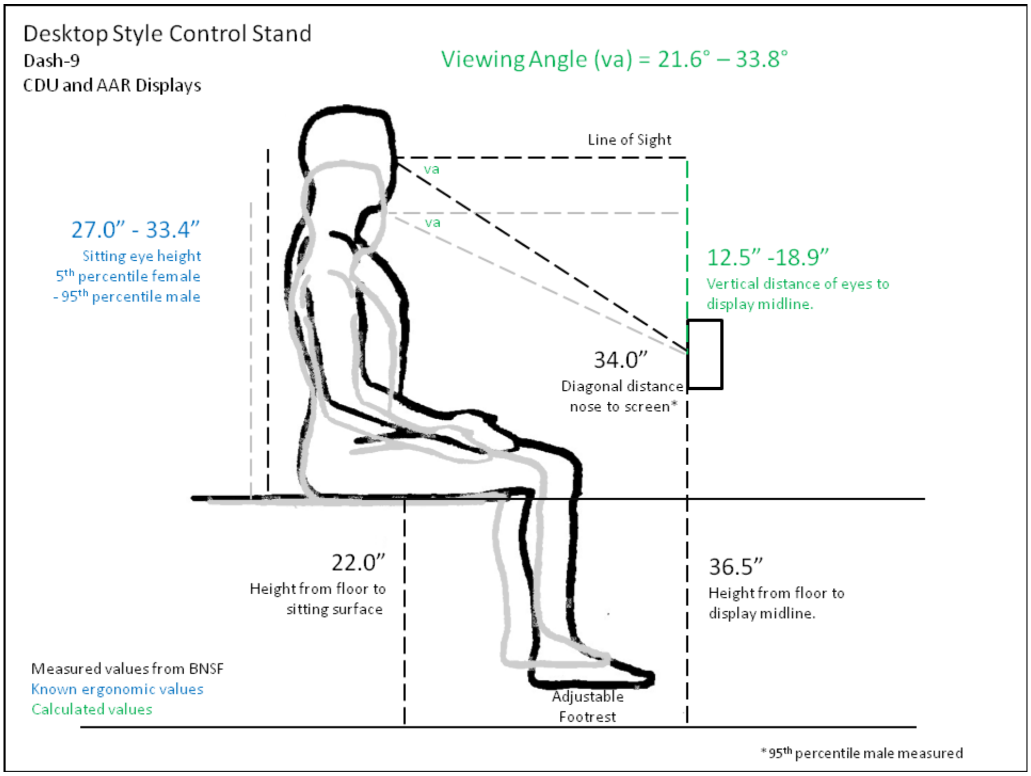

FIGURE 1: DESKTOP STYLE CONTROL STAND, DASH-9, AAR AND CDU DISPLAY – VIEWING ANGLE

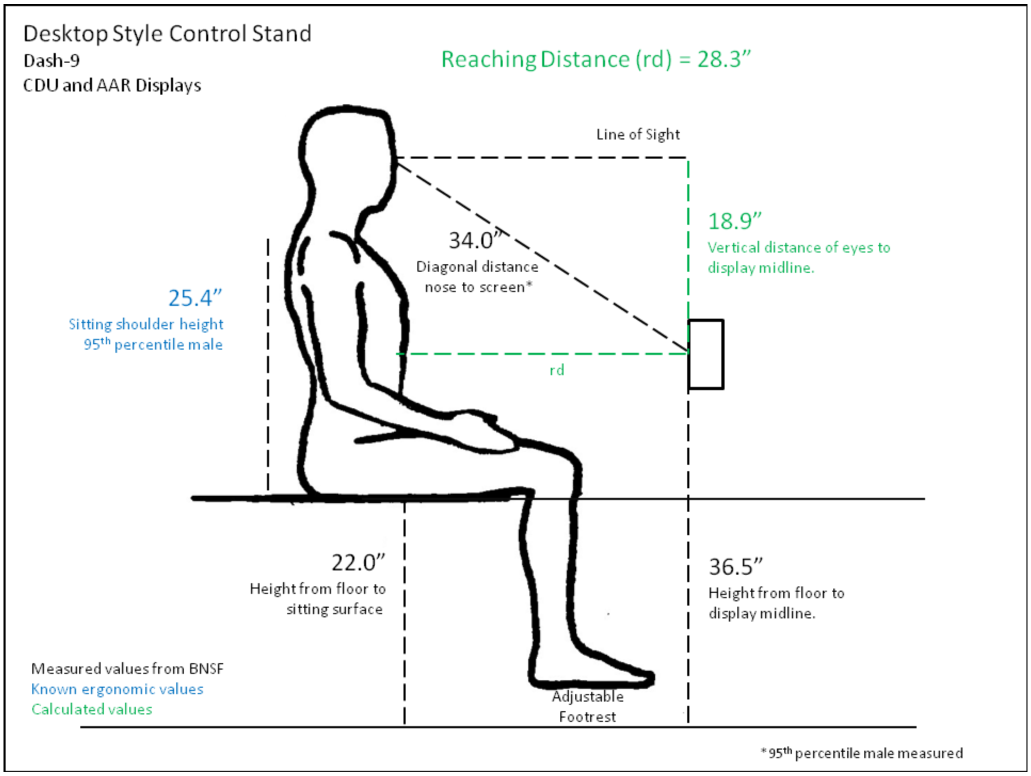

FIGURE 1: DESKTOP STYLE CONTROL STAND, DASH-9, AAR AND CDU DISPLAY – REACHING DISTANCE

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.

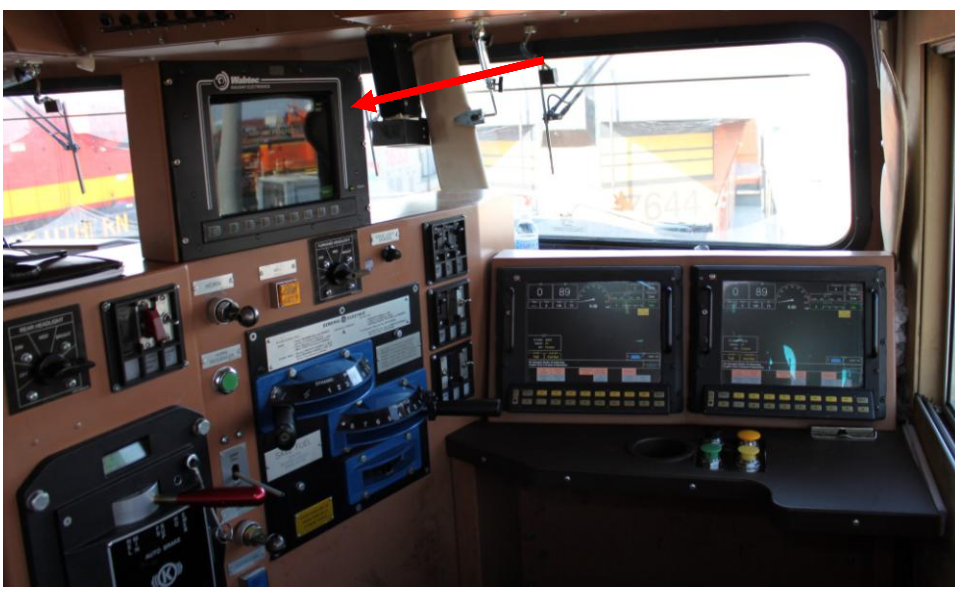

FIGURE 1: AAR STYLE CONTROL STAND – VIEW 1

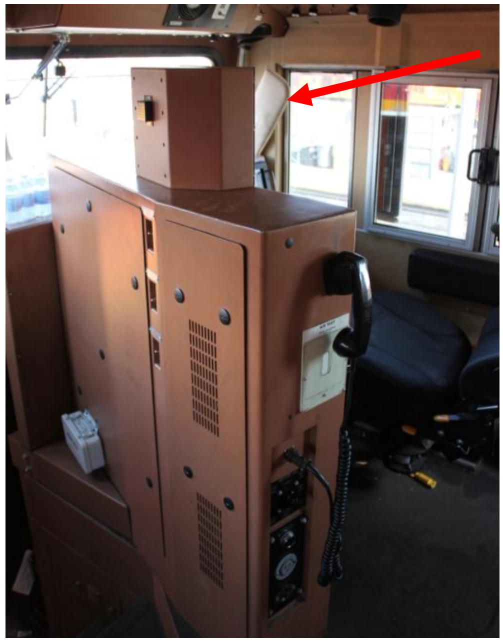

FIGURE 1: AAR STYLE CONTROL STAND – VIEW 2

TABLE 4 –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 5 –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

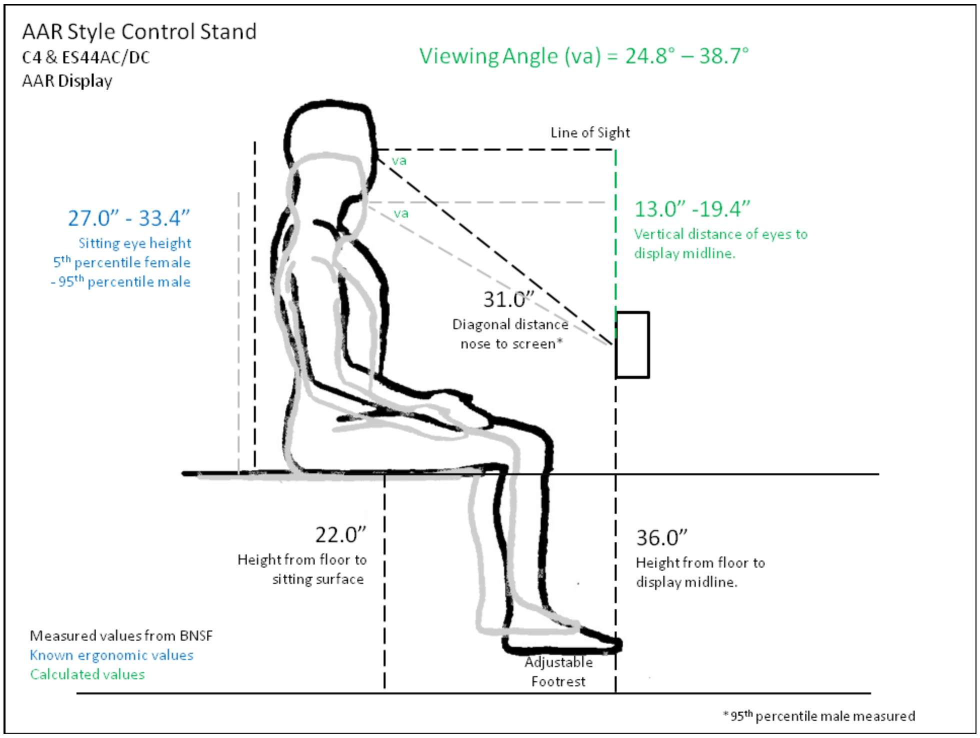

FIGURE 1: AAR STYLE CONTROL STAND, C4 & ES44AC/DC AAR DISPLAY – VIEWING ANGLE

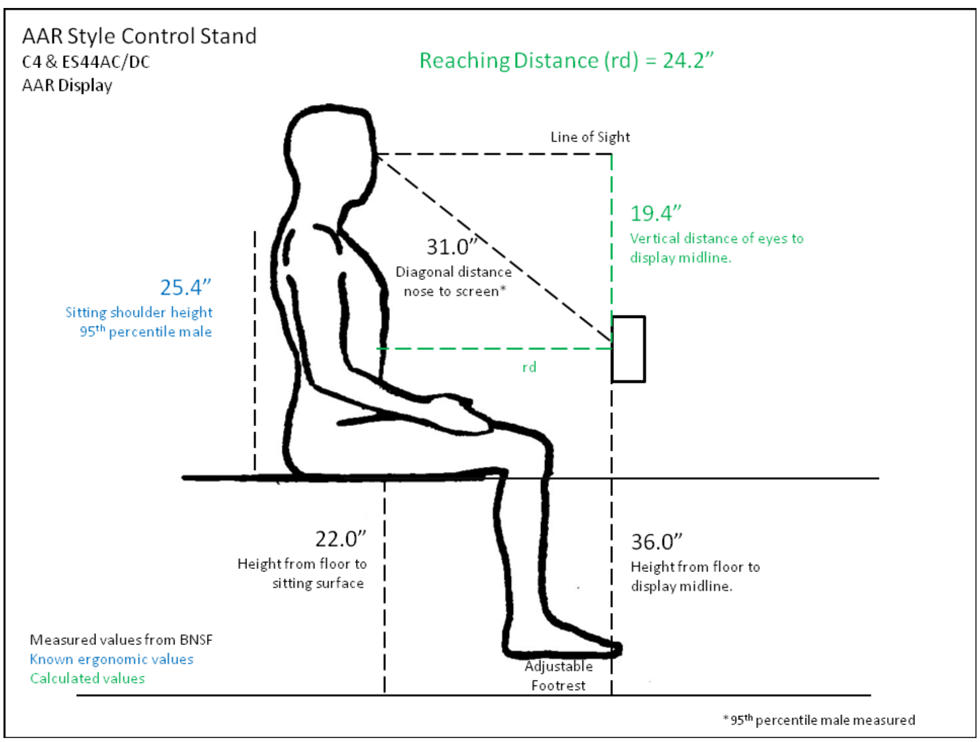

FIGURE 1: AAR STYLE CONTROL STAND, C4 & ES44AC/DC AAR DISPLAY – REACHING DISTANCE

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**

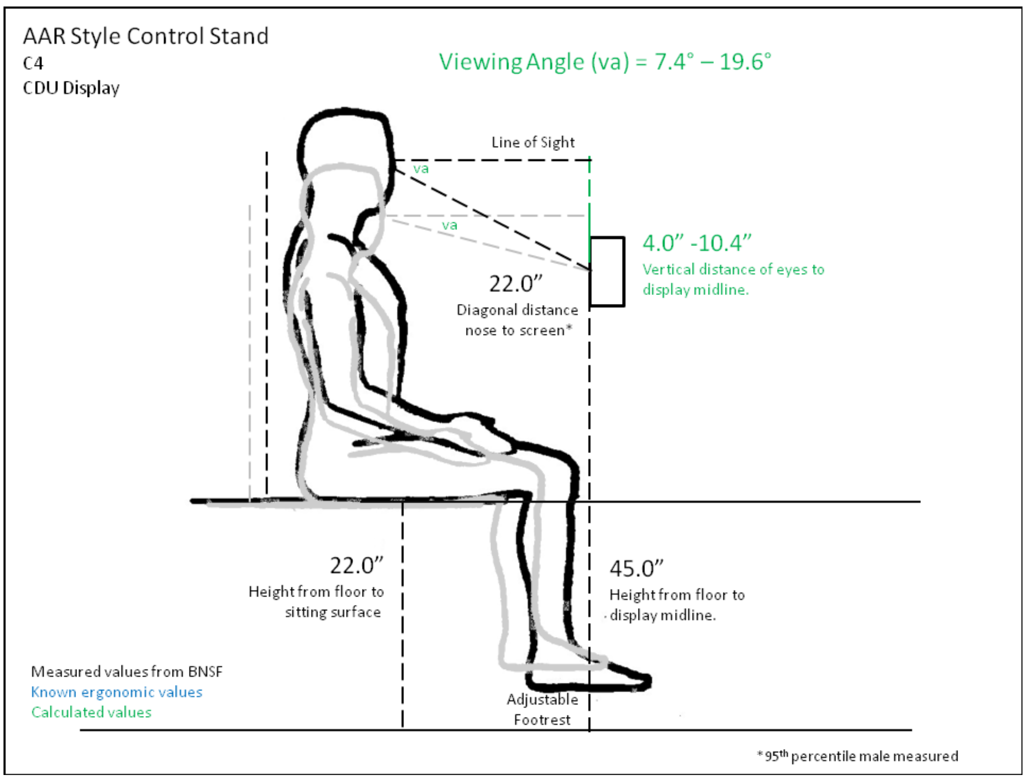

FIGURE 1: AAR STYLE CONTROL STAND, C4 CDU DISPLAY - VIEWING ANGLE

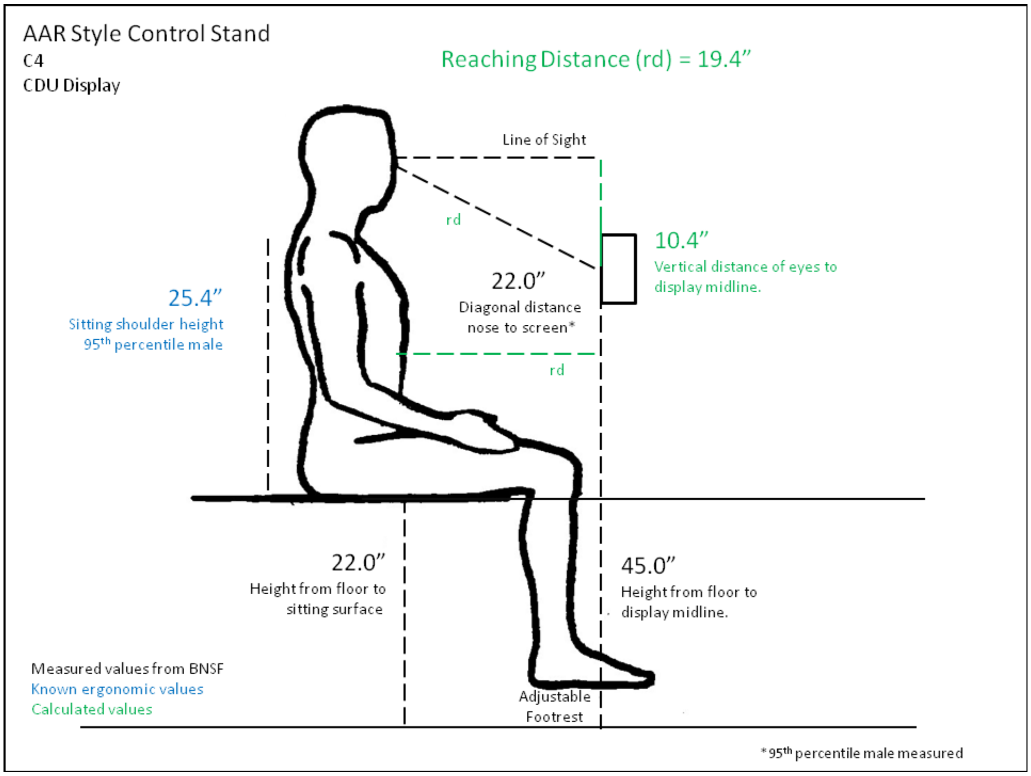

Figure 1: AAR Style Control Stand, C4, CDU Display - Reaching Distance

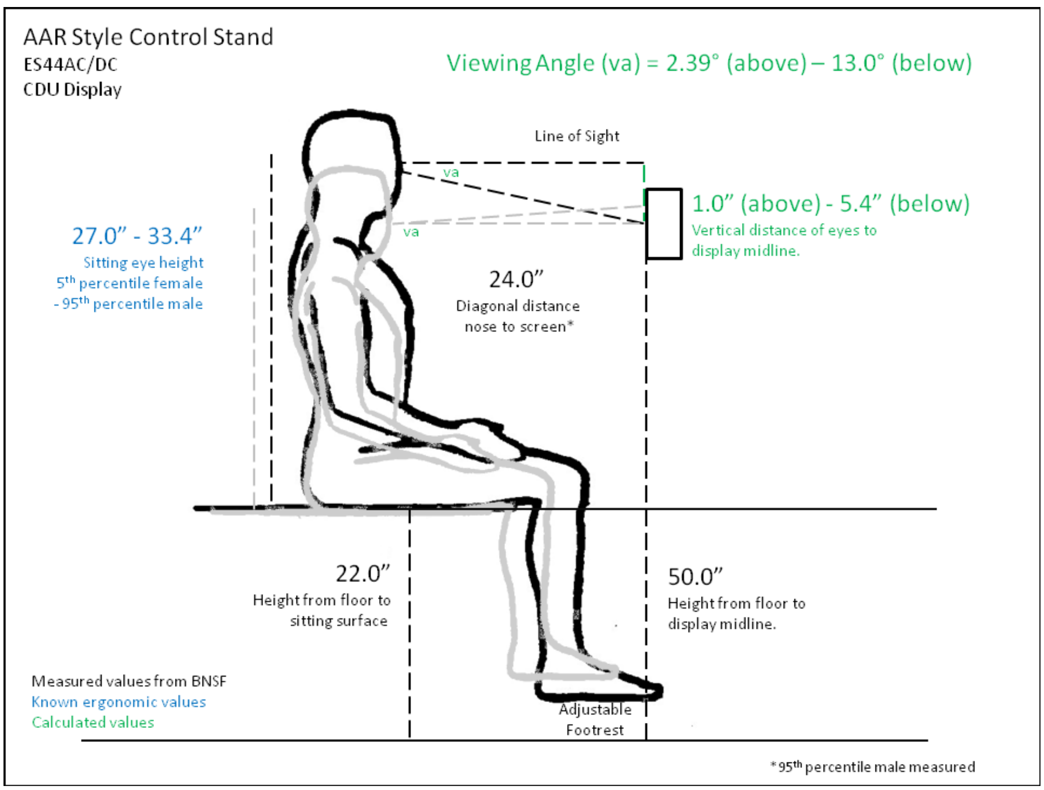

Figure 1: AAR Style Control Stand, ES44AC/DC CDU Display - Viewing Angle

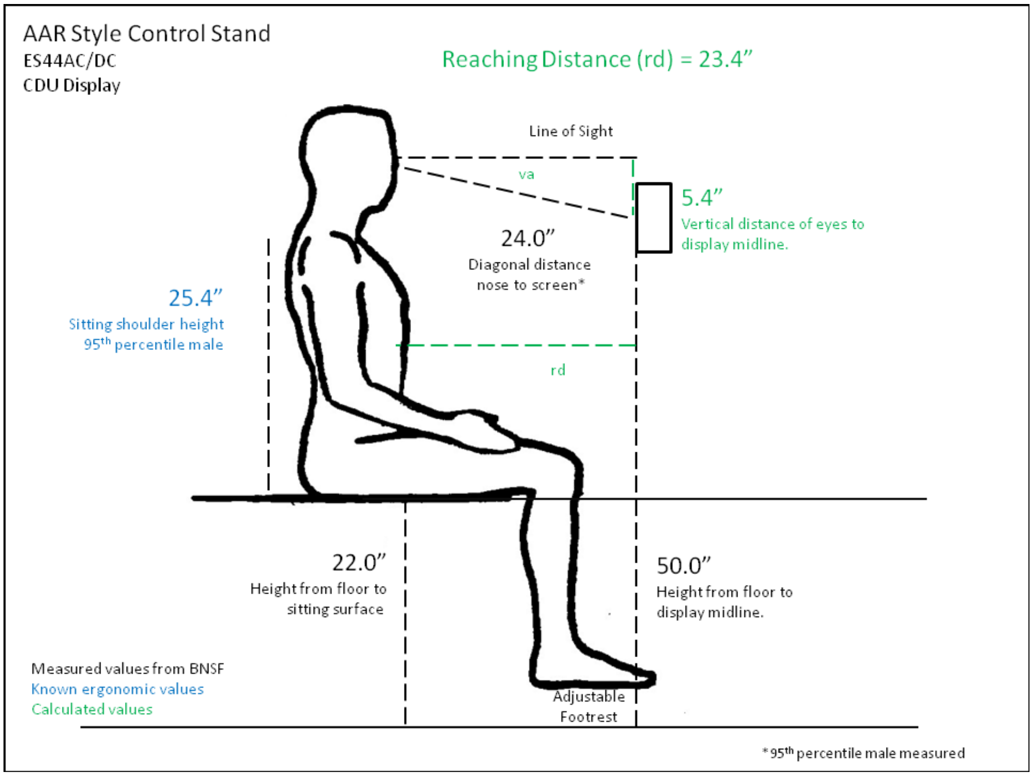

FIGURE 1: AAR STYLE CONTROL STAND, ES44AC/DC CDU DISPLAY - REACHING DISTANCE

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.