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13. ABSTRACT (Maximum 200 words)

This report summarizes work to develop a set of preliminary human factors functional design guidelines for remote control locomotive (RCL) systems, in particular the design of the operator control unit (OCU). To carry out the work, researchers first conducted a human factors analysis of existing RCL OCUs to better understand current OCU designs. Analysis looked for instances of 13 different human factors design issues that can induce human error. The research team analyzed four different OCUs. Human factors issues that were found included: 16 instances of inappropriate use of color in displays, 15 instances of poor color choices for critical controls, 12 instances of symmetry issues, 5 adjacency issues, and 1 instance of a critical control that was not protected. Next, researchers identified emerging technologies and capabilities that may be incorporated into next generation RCL systems. Third, human factors standards and guidelines relevant to RCL systems were reviewed. Lastly, a preliminary set of human factors, top-level functional design guidelines are recommended. Researchers identified and organized a total of 51 preliminary human factors functional design guidelines into the following 7 categories: general design, general function, feedback, labels, use of color, visual displays and indicators, and auditory displays and alarms. More work is suggested to advance the guidelines to a final form.

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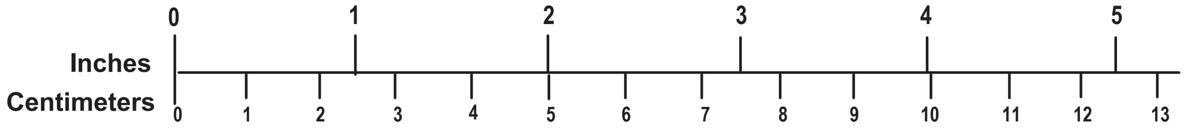

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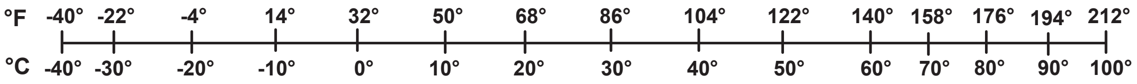

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Preface

The purpose of this project was to develop a set of preliminary human factors functional design guidelines for remote control locomotive (RCL) systems. This work is part of a larger Federal Railroad Administration (FRA) research program examining potential safety issues related to RCL operations. This research was performed under FRA Office of Research and Development Contract DTFR53-01-D-00029.

The authors would like to thank a number of individuals who assisted in this research. First, the authors would like to express thanks in particular to Mr. Michael Jones, FRA Office of Research and Development Human Factors Program, for sponsoring the research and providing programmatic and technical support.

Thanks are also due to each of the major RCL suppliers—Cattron, General Electric, and Control Chief—for their provision of RCL operating instructions and cooperation. Thanks are also due to Mr. Jeff Moller and Mr. Howard Moody, Association of American Railroads, and Mr. Bernie Sanders, CSX Transportation, for reviewing and providing critical feedback to early versions of a white paper on the incorporation of human-systems integration into the railroad industry (see Appendix B). Thanks are also due to Ms. Nathalie Lewis and Mr. Maury Hill, Transportation Safety Board of Canada, for assisting in the provision and interpretation of Canadian RCL accident/incident data.

The authors also wish to thank Dr. Vic Riley, User Interaction Research & Design, for providing user interaction expertise from time to time to help validate results of the RCL operator control unit analysis. Lastly, the authors wish to thank Ms. Susan McDonough, Foster-Miller, for providing administrative and programmatic support to the project and authors, and for reviewing a draft of the final report and providing valuable feedback.

Executive Summary

U.S. Class I freight railroads have used remote control locomotive (RCL) operations in railroad switching yards since the start of 2002. Although remote control technology has existed for decades, including use in mines and other industrial applications, the safety implications associated with RCL operations in the U.S. railroad industry have just recently begun to be identified and analyzed. As part of this effort, the Federal Railroad Administration (FRA) Office of Research and Development Human Factors Program and FRA Office of Safety initiated a multiple study program of research into RCL operations. The first three studies examined RCL safety from an operational and procedural perspective.

This report summarizes the fourth FRA-sponsored study of RCL operations. The aim of this fourth study was to examine the technology from a human factors perspective—specifically the interaction between remote control operator (RCO) and the RCL operator control unit (OCU). The goal of the study was to produce a preliminary set of human factors functional design guidelines for RCL operations, with particular emphasis on the design of the OCU. Human factors guidelines exist for locomotive cabs, and FRA recently revised a regulation in the Code of Federal Regulations (CFR) governing train control systems that provided human factors engineering (HFE) guidance. Human factors guidelines for RCL operations complement these other FRA efforts.

Through careful consideration of the interaction between operator and technology, human factors functional design guidelines can help reduce design-induced operator error, thereby increasing human reliability and operational safety. Furthermore, functional, or performance-oriented, guidelines provide guidance on what the OCU or system *should* be able to do, but not *how* the OCU or system should do it. This high-level approach not only helps to ensure that human factors principles are considered and included but also provides suppliers with the flexibility to design RCL systems and their OCUs according to their own design philosophies.

To carry out the work, researchers first conducted a human factors analysis of existing RCL OCUs to better understand current OCU designs. Analysis was based in large part on application of the Human-Centered Technologies Tool (HCTOOL), an experimental human factors evaluation software tool developed under FRA sponsorship. Analysis looked for instances of 13 different human factors design issues that can induce human error. Human factors issues include:

- Instances of poor color choices for critical controls
- Controls using a critical function color but not marked as hazardous
- Adjacency issues
- Symmetry issues
- Associated control and display movement issues
- Poor color contrast choices
- Instances of confusing movement directions
- Instances of reversed movements

- Inconsistent function key/display screen pairs
- Instances of no display feedback for controls
- Instances of an unusual number of positions
- Instances of critical controls not being protected
- Instances of inappropriate use of colors in displays

Each of the major RCL suppliers provided documentation and illustrations to support analyses. The research team analyzed a total of four different OCUs. The goal of the analysis was to look at the design of the OCUs as a group, not to examine or critique any one OCU design. The value in conducting the analysis was in obtaining an understanding of the extent to which HFE appears to be incorporated into OCU designs as a whole. Human factors issues that were found included: 16 instances of inappropriate use of color in displays, 15 instances of poor color choices for critical controls, 12 instances of symmetry issues, 5 adjacency issues, and 1 instance of a critical control that was not protected.

Researchers next identified emerging technologies and capabilities that may be incorporated into next generation RCL systems. The following emerging technologies were identified: integration of RCL systems with over-the-road main track systems and operations; integration of remote switch lining capability; remote video monitoring; impact detection; integration of dynamic and automatic (i.e., blended) brakes; provision of additional feedback to the RCO; and a change in weight, size, and dimension of the OCU.

Third, the team reviewed human factors standards and guidelines that were relevant to RCL systems. Reference sources that were reviewed include FRA and Association of American Railroad (AAR) materials, domestic and international standards such as the American National Standards Institute (ANSI) and the International Organization for Standardization (ISO), and software user interface guideline references.

Based on the information provided by the OCU analysis, information on possible emerging RCL technologies, and relevant human factors guidelines and standards, a preliminary set of top-level human factors functional design guidelines is recommended. The guidelines development process included identification of human factors technical issues related to the design of the OCU. These technical issues included situation awareness, task and information overload, trust and overreliance, inadvertent activation, and interaction with OCU training and experience. Most of these issues are not specific to RCL operations, but rather they address common issues related to the interaction between a human operator and any technological system used to carry out work. As such, they may influence the development of human factors functional design guidelines for RCL OCUs.

A total of 51 human factors functional design guidelines were identified and organized into the following 7 categories: general design, general function, feedback, labels, use of color, visual displays and indicators, and auditory displays and alarms. Many of the RCL OCU guidelines were adopted from Multer, Rudich, and Yearwood's *Human Factors Guidelines for Locomotive Cabs* since locomotive operations and RCL operations share a number of commonalities.

General design guidelines include top-level suggestions that address the overall design of the OCU. Some are quite broad in nature, while others address the physical properties or locations of controls and displays. General function guidelines address general OCU functionality.

Feedback guidelines address the need for and importance of providing feedback to the RCO. Label guidelines address labels for various controls and displays. Color guidelines discuss the appropriate use of color for OCU controls and displays. Visual display and indicator guidelines address the design of visual displays, including indicator lights and clusters. Auditory display and alarm guidelines address the design of auditory displays and alarms. In general, alarms include nonverbal warnings and alerts, although alarms can include speech messages. Alarms are used to warn an RCO of a time-sensitive or safety-critical situation that requires RCO action or attention. Examples of each type of guideline are presented below.

General Design:

- Displays should be located as close as possible to the controls for which they provide feedback.
- The OCU should be designed to minimize the amount of heads-down time where an RCO is looking at the OCU.
- The OCU should be designed to protect against inadvertent activation of controls, caused by reaching in to make air hoses, lining switches, climbing ladders, and tying hand brakes, for example, or by bumping one control while trying to activate an adjacent one.

General Function:

- The OCU should enable an RCO to recover from accidental activation of a control (a.k.a. error recovery or reversible action) whenever practical.
- The OCU should be capable of displaying programmable running time and/or distance traveled information.
- The OCU should be equipped with an emergency stop control.

Feedback:

- Each control actuation or other RCO input should produce a perceptible response output.
- The OCU should provide feedback on RCO-requested actions, the state of the RCL system, and the state of the RCL, as close in time as possible with the requested action, change in RCL system state, or change in RCL state.
- Feedback should clearly indicate the corrective action to take when a system failure or error occurs.

Labels:

- Labels should use words and abbreviations that are familiar to the RCO.
- Labels should use concise wording.

Use of Color:

- Safety-critical controls and displays should be color coded red (for the most safety-critical controls/displays, such as equipment failures) or yellow/amber (for less critical controls/displays, such as warnings).
- Permissive controls and displays should be color coded green.

- Neutral controls and displays (including indicator lights and non-critical visual messages) should be color coded something other than red, yellow/amber, or green.
- Use of colors in displays should be limited.

Visual Displays and Indicators:

- Where abbreviations are necessary, the OCU should employ simple, familiar, and easy-to-understand abbreviation forms.
- OCUs should employ common abbreviations and avoid abbreviations that are ambiguous or that can be misinterpreted.
- Icons, symbols, and graphics should be simple, easy to recognize, and representative of the nature for which they are used.

Auditory Displays and Alarms:

- When speech is employed, natural speech displays should be used rather than synthetic speech to increase comprehension.
- Alarms should be used to present high-priority, critical, and urgent information (e.g., in cases where an RCO must respond immediately to avoid a hazard).
- Alarms should convey the level of danger or risk associated with the warning.

Each of the four OCUs that were analyzed exhibited designs that were consistent with at least several of the guidelines that were developed. Researchers, however, did not perform an analysis of the precise extent to which OCUs conformed to the 51 guidelines.

Lastly, the report provides two recommendations for future research to advance the guidelines from their preliminary form to a mature, ready-to-use set of guidelines that RCL suppliers can adopt.

1. Introduction

Section 1 presents a brief background to the research described in this report; discusses the objectives, overall approach, and scope of the work; and concludes with a layout of the organization of this report.

1.1 Background

U.S. Class I freight railroads have used RCL operations in railroad switching yards since the start of 2002. RCL operations consist of three components: the locomotive (the RCL), an onboard control computer (OCC) (see Figure 1) that interfaces with the RCL's controls (and usually mounted somewhere inside or on the RCL), and a portable OCU. An RCO typically wears the OCU harnessed to a vest (see Figure 2). In RCL operations, one or two crewmembers (one or both are RCOs) switch cars, commanding the locomotive to move via inputs to the OCU rather than radio or hand signals to the locomotive engineer on board the locomotive. When an RCO wants to send a command to the RCL (e.g., to slow down), the RCO manipulates hand controls on the OCU. The OCU, in turn, transmits these inputs via radio frequency to the OCC. The OCC then actuates locomotive commands by interfacing with the locomotive. Figure 3 illustrates the basic concept of RCL operation. Using RCL operations, an RCO on the ground can directly control the locomotive (see Figure 4) rather than communicate movement directions to a locomotive engineer stationed on board the locomotive. The RCO in control of the move is often referred to as the A or primary RCO, while the second RCO is referred to as the B or secondary RCO. The A operator has all of the RCL functions available to control the RCL while the B operator has access to a limited set of safety-related redundant functions, such as the locomotive's horn and emergency brake application.

Figure 1. OCC

[redacted]

Figure 2. RCO with OCU

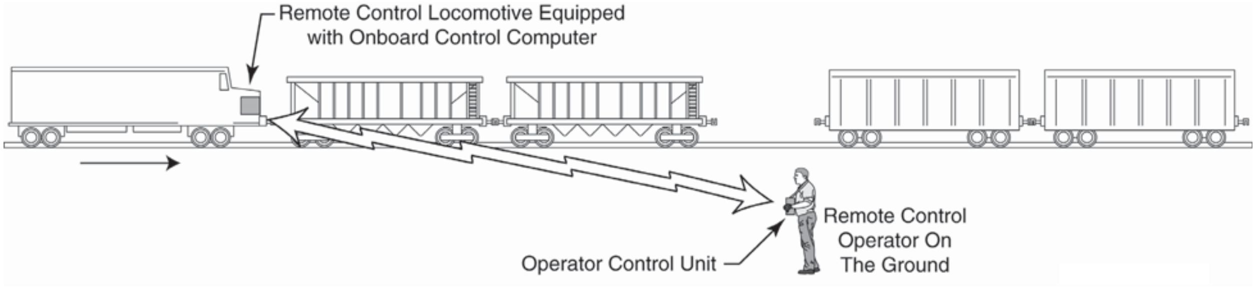

Figure 3. Basic illustration of RCL operation

Figure 4. RCO making coupling

RCL operating environments include yards, industrial spurs and sidings, and, most recently, some main tracks and sidings/spurs. RCOs must adhere to all relevant operating rules in effect during RCL operations and may have additional responsibilities depending on the operating environment. Some of these responsibilities may include communication with a yardmaster or train dispatcher, minor train handling on ascending and descending grades, car handling, and communication with other crews operating in the RCOs' vicinity. A majority of the RCOs on U.S. Class I railroads are switchmen who receive additional RCL training to qualify as an RCO, although a small number of RCOs on U.S. Class I and some regional railroads are also qualified locomotive engineers who have experience operating a locomotive. Traditionally, switchmen were not trained to operate a locomotive.

Although the remote control technology has been around for decades, including use in mines and other industrial applications, the particular safety implications of RCL operations in the U.S. railroad industry and reducing crew size in switching operations have just recently begun to be identified. FRA held a technical conference with industry stakeholders on RCL operations in 2000 and has subsequently issued several Safety Advisories to support the safe implementation of RCL operations (e.g., FRA, 2001; FRA, 2007).

To further enhance its understanding of the safety implications of RCL operations, especially the human factors issues related to RCL operations, FRA Office of Research and Development Human Factors Program and FRA Office of Safety also initiated a multiple study program of research into RCL operations in early 2002, just as RCL operations began on a large scale in the United States. FRA initially sponsored three studies: a comparative risk assessment of RCL and yard switching operations (see Reinach, Fadden, Gamst, Acton, & Bartlett, 2006), a root cause analysis of RCL-involved train accidents/incidents (see Reinach & Viale, 2006), and focus groups with RCOs to identify safety-related issues and best practices (see Reinach & Acton, 2006).

These three research studies examined RCL safety from an operational and procedural perspective but not from an HFE perspective, where the technology's capabilities of control provided to users (i.e., the OCU) can be assessed. In fact, a recent survey of RCOs suggests that the design of the OCU may contribute to some types of operator errors (Gamst & Gavalla, 2005). Use of HFE methods to examine new technology where a human interface exists is advantageous because it can reduce development and lifecycle costs while increasing safety. HFE is part of a larger approach to technology acquisition and modernization called human systems integration (HSI). HSI is a combination of managerial philosophy, methods, techniques, and tools designed to emphasize, during the acquisition or modernization process, the central role and importance of users in organizational processes or technologies. This approach optimizes the safety and efficiency of these systems through the consideration of all the system's elements.

This report summarizes the fourth FRA-sponsored study of RCL operations. The aim of this fourth study was to focus on HFE elements of RCL operations through an examination of the interaction between the OCU and RCO and the development of a preliminary set of human factors functional design guidelines for RCL operations, with particular emphasis on the design of the OCU. Human factors guidelines exist for locomotive cabs (Multer, Rudich, & Yearwood, 1998), and FRA recently revised a regulation in the CFR governing train control systems that provided HFE guidance (49 CFR § 236, Appendix E, 2005). Human factors functional design guidelines for RCL operations, therefore, complement FRA's other efforts to introduce HFE to the railroad industry and into railroad technology development and implementation. Furthermore, AAR RCL Standard S-5507 (AAR, 2006) suggests that consideration be given in the design of the OCU to human factors principles (see Section 4.1.20). Therefore, development of human factors functional design guidelines for RCL OCUs is also consistent with AAR's voluntary industry standard for RCL systems.

1.2 Objectives

The overall objective of the study was to examine potential RCL operations safety issues related to use of the OCU. This was accomplished through examination of the interaction between the OCU and RCO, as well as the development of a preliminary set of human factors functional design guidelines for RCL operations, with particular emphasis on the design of the OCU.

1.3 Overall Approach

To carry out the work, researchers established several goals:

- Conduct a human factors analysis of existing RCL OCUs to better understand current OCU designs.
- Identify emerging technologies and capabilities that may be incorporated into next generation RCL systems.
- Review relevant supporting documents that address human factors issues related to RCL systems.
- Generate a preliminary set of human factors, top-level functional guidelines for the design of RCL systems, with particular emphasis on the OCU.

Through careful consideration of the interaction between operator and technology, human factors functional design guidelines can help reduce design-induced operator error, thereby increasing RCL operational safety. Furthermore, functional, or performance-oriented, guidelines provide guidance on what the OCU or system *should* be able to do but not *how* the OCU or system should do it. This high-level approach not only helps to ensure that human factors principles are considered and included but also provides suppliers with the flexibility to design RCL systems and their OCUs according to their own design philosophies.

1.4 Scope

The scope of the research was limited to an RCO's interaction with RCL systems, with particular emphasis on the OCU. This work does not address operational and procedural performance issues; FRA has addressed these issues in previous research (e.g., see Reinach & Viale, 2006). The human factors functional design guidelines are preliminary in nature. They should be viewed as a first cut at producing an industry-accepted set of rational, research-based design guidelines. The guidelines address the functions of the RCL OCU that affect the interaction or interface between the OCU and RCO. The guidelines do not address other safety issues, such as the ability of the OCU to withstand a certain amount of shock or impact (impact and drop tests), and they do not address design for OCU maintenance and repair. The research team developed the guidelines based on a brief industry review of supporting standards, guidelines, and advisories, as well as application of human factors expertise. The guidelines, however, are not based on a thorough review and application of relevant human factors research or human-computer interaction guidelines, and therefore, they should not be currently viewed as authoritative. Furthermore, the guidelines are designed to provide top-level functional direction, not detailed design requirements or specifications.

The preliminary guidelines address the current form of the RCL OCU—a small boxlike device typically worn on a vest and positioned in front of the RCO's stomach or chest (see Figure 2). Some guidelines, therefore, may not be applicable to future OCU designs that vary from this boxlike form.

Lastly, results of the OCU human factors analyses were not validated by RCL suppliers to ensure that analyses were based on correct interpretation of each OCU's functions and capabilities. Results of the OCU analyses, therefore, should be considered preliminary.

1.5 Organization of the Report

This report is divided into several sections. Section 2 presents results from the human factors analysis of existing RCL OCU interfaces based on a human factors analysis software tool developed under sponsorship by FRA's Office of Research and Development Human Factors Program. Section 3 presents a preliminary set of human factors functional design guidelines for RCL systems. Section 4 summarizes this research effort by identifying the key findings and providing some recommended next steps in the development of human factors functional design guidelines. Section 5 presents a list of references used in this research. The report also includes two appendices. Appendix A describes an early effort to analyze U.S. and Canadian railroad accidents/incidents involving RCL operations to determine whether or not the design of the RCL OCU contributed to any of the accidents/incidents. Limitations inherent in the U.S. and Canadian accident/incident databases and data collection methodologies prevented gleaning any information about the possible contribution of OCU design to accidents/incidents. Appendix A discusses these limitations in greater detail. Appendix B provides additional information on HSI and how it may be applied to the U.S. railroad industry. Finally, a list of abbreviations and acronyms used in this report follows the appendices.

2. Human Factors Analysis of Current RCL OCUs

The purpose of analyzing existing RCL OCUs was to learn more about the existing design from a human-centered perspective. Researchers used FRA's HCTOOL, an automated human factors analysis tool, to analyze OCUs from each of the major RCL suppliers: General Electric (GE), Cattron, and Control Chief. To support analyses, each of these major RCL suppliers provided operating instructions and photographs under a nondisclosure agreement. The goal of the analysis was to look at the design of the OCUs as a group and not to examine or critique any one OCU design. The value in conducting the analysis is in obtaining an understanding of the extent to which HFE appears to be incorporated into OCU designs as a whole.

To use HCTOOL, a user first uploads an image of an interface to the tool. Next, an analyst goes through a series of steps to assign and characterize the physical and functional attributes of all controls and displays using a built-in set of physical and functional descriptors. HCTOOL then analyzes the interface based on a built-in human factors knowledge base. HCTOOL analyzes interfaces for the following 12 types of human factors issues:

- *Instances of poor color choices for critical controls*. Lists the number of controls that operate critical functions but whose color does not indicate that the functions are critical.
- *Controls using a critical function color but not marked as hazardous.* Lists the number of yellow- or red-colored controls not defined to have critical functions.
- *Adjacency issues*. Lists the number of controls and displays adjacent to identical controls or displays, and the functions assigned to the controls and displays in question are such that operating a control, or reading a display, when intending to use the adjacent control or display, could result in a hazardous condition.
- *Symmetry issues*.[1] Lists the number of controls and displays that are symmetrical, and the functions assigned to the controls and displays in question are such that operating a control, or reading a display, when intending to use the symmetrical control or display, could result in a hazardous condition.
- *Associated control and display movement issues.* Lists the number of controls and displays where the movement of a control conflicts with the movement of the associated display.
- *Poor color contrast choices*. Lists the number of graphical display elements (icons, text, etc.) whose colors result in low contrast with the graphic region background color they are on (such as purple text on a black background).
- *Instances of confusing movement directions*. Lists the number of controls or displays that violate cultural conventions in their movement directions (such as increasing a value by moving a control down instead of up or moving a control left instead of right).

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[1] The final version of HCTOOL does not contain a symmetry check. The version of HCTOOL used for this analysis was a pre-final, beta version of the tool.

- *Instances of reversed movements.* Lists the number of instances in which two controls or display elements of the same type operate in opposite directions (such as a toggle switch that turns its function on when pushed up and another that turns its function on when pushed down).
- *Inconsistent function key/display screen pairs*. Lists the number of instances in which potentially incompatible functions (such as CANCEL and OK) are assigned to the same function key on different screens.
- *Instances of no display feedback for controls*. Lists the number of controls that do not have associated displays and therefore lack appropriate feedback concerning the functions operated by those controls.
- *Instances of an unusual number of positions*. Lists the number of controls that have more than the recommended number of positions for the control type (such as a rocker switch with more than three positions).
- *Instances of critical controls not being protected*. Lists the number of critical but infrequently used controls that can lead to a hazardous condition when inadvertently activated. These controls should be protected from inadvertent operation.

See Riley, Reinach, and Green (2007) for more information on development and use of the HCTOOL. For a brief description of tool development, see Riley, Reinach, Bruck, and Raslear (2005).

In addition to the 12 types of human factors issues analyzed by the HCTOOL, 2 subject matter experts (SMEs) analyzed 1 additional human factor issue among all OCUs:

- *Instances of inappropriate use of colors in displays.* Lists the number of display clusters where red, yellow/amber, and green were inappropriately used (i.e., were used for something other than their cultural convention). Red usually indicates stop or hazard, yellow or amber indicates caution, and green indicates a permissive state (e.g., Go).

The current version of the HCTOOL does not check for this issue, although it does check for separate but similar issues of color with respect to controls.

A precedent exists for analyzing existing technologies as part of developing human factors functional design guidelines. Lerner, Jenness, Singer, Huey, and Llaneras (2007) recently analyzed existing highway-rail intersection technologies and used the results to support development of human factors guidelines for intelligent transportation systems at highway-rail intersections.

2.1 RCL OCU Analysis Method

Researchers analyzed four different RCL systems' OCUs: the blue GE OCU, the yellow Control Chief OCU, and Cattron's green Accuspeed and orange Beltpack (formerly CANAC) OCUs. HCTOOL is a prototype tool designed to be able to analyze almost any interface in any context or application. In fact, HCTOOL was developed with several railroad technologies in mind, including positive train control (PTC) and RCL OCUs. HCTOOL had some shortcomings, however, in terms of its ability to characterize an OCU using the tool's built-in set of control and display attributes. Furthermore, occasionally the OCU operating instructions did not provide enough information to support analysis. To facilitate analyses, the research team occasionally contacted OCU suppliers and the architect of HCTOOL, Dr. Vic Riley, to provide clarification. Finally, a number of assumptions about the OCUs and/or HCTOOL were made where information gaps still existed about HCTOOL or one or more OCUs. These assumptions include the following:

- Where controls had capabilities or functional attributes that were not covered by HCTOOL, analysts assigned multiple (typically, two) controls on top of each other to simulate multifunctionality. For example, on some OCUs, one pushbutton may serve two functions using two different types of functional logics. In one case, an RCO presses and releases the pushbutton to activate the vigilance button or presses and holds for at least 2 seconds to activate sanding.
- To facilitate analysis, analysts assumed that OCU controls located on a diagonal plane between the top and front of the OCU were located on the front of the OCU. The current version of the HCTOOL software does not offer the front, angled plane as an option to select when assigning and defining the physical attributes and locations of controls and displays. Current options for RCL OCUs include the top, bottom, left, right, and front.
- To facilitate analysis, analysts assumed that the OCU power control located on a plane between the right side and the bottom of one of the OCUs was located on the bottom of the OCU. The current version of the HCTOOL software does not offer this angled plane as an option to select when assigning and defining the physical attributes and locations of controls and displays. Current options for RCL OCUs include the top, bottom, left, right, and front.
- To facilitate analysis, analysts assumed that silver toggle switches were grey. The current version of the HCTOOL software does not offer silver as a color option to select when assigning and defining the physical attributes and locations of controls. Gray was the closest color offered.

Analysts conducted human factors analysis of each OCU in two phases. First, each OCU was analyzed using HCTOOL. Next, two SME analysts reviewed the results generated by the HCTOOL and either accepted or rejected each finding based on their knowledge of human factors and RCL operations. The two SME analysts also looked for instances of inappropriate use of colors in OCU displays. One condition that analysts used in deciding whether to accept or reject an HCTOOL finding was to re-evaluate whether or not controls and displays could lead to a hazardous condition. Analysts used the following definition of a hazardous condition: a hazardous condition is present when (1) purposefully or accidentally activating a control (in a single step) changes the task's condition/status without feedback or warning to the RCO and/or creates an otherwise unsafe condition (e.g., operator intends to stop with speed selector, but commands the RCL to go faster by mistake) or (2) not being able to quickly locate, distinguish, or activate a control creates an unsafe condition (e.g., a delay in sounding the RCL horn to avoid somebody walking in front of the RCL may result in an injury). In general, the original number of HCTOOL findings was significantly reduced after review. This report documents the results of this two-phase analysis.

RCL suppliers did not validate the results of the OCU human factors analyses to ensure that they were based on correct interpretation of each OCU's functions and capabilities. Results of the OCU analyses, therefore, are preliminary. Ultimately, results of each analysis should be discussed with the RCL supplier whose equipment was analyzed to ensure accurate and meaningful results.

2.2 RCL OCU Analysis Results

Of 13 possible types of human factors issues, researchers identified the following 5 types among the 4 OCUs:

- *Instances of poor color choices for critical controls*. Lists the number of controls that operate critical functions but whose color does not indicate that the functions are critical.
- *Adjacency issues*. Lists the number of controls and displays that are adjacent to identical controls or displays, and the functions assigned to the controls and displays in question are such that operating a control, or reading a display, when intending to use the adjacent control or display, could result in a hazardous condition (substitution error).
- *Symmetry issues*. Lists the number of controls and displays that are symmetrical, and the functions assigned to the controls and displays in question are such that operating a control, or reading a display, when intending to use the symmetrical control or display, could result in a hazardous condition (substitution error).
- *Instances of critical controls not being protected*. Lists the number of critical but infrequently used controls that can lead to a hazardous condition when inadvertently activated. These controls should be protected from inadvertent operation.
- *Instances of inappropriate use of color in displays*. Lists the number of display clusters where red, yellow/amber, and green were inappropriately used (i.e., were used for something other than their cultural convention).

Table 1 presents the results of the HCTOOL analyses by issue and OCU. Specific RCL manufacturers are not identified since the purpose of the analysis was to look at available OCUs as a whole and not to critique any one RCL supplier or OCU.

Table 1. OCU analysis results by human factors design issue and OCU

	OCU				
Human Factors Design Issue	**A**	**B**	**C**	**D**	**Total**
Adjacency	0	0	1	4	**5**
Critical controls not protected	0	0	0	1	**1**
Inappropriate use of color in displays	4	4	4	4	**16**
Poor color choices for critical controls	3	4	3	5	**15**
Symmetry	3	3	3	3	**12**
Total	**10**	**11**	**11**	**17**	**49**

The most prevalent human factors design issues centered on color. The most frequent issue was instances of inappropriate use of color in displays (n=16). This was an issue with all four OCUs analyzed. An example of color misuse in displays is the use of amber or red to indicate speed settings (e.g., 10 mph) other than stop (red is an appropriate color to indicate stop). Cultural convention suggests that speed indicators should be colored green (for go).

The next most frequent issue was poor color choice for critical controls (n=15). This was also an issue with all four OCUs. An example of poor color choice is the independent brake selector's color black. The independent brake is a critical function because not being able to quickly locate, distinguish, or activate it can create an unsafe condition (i.e., not stopping the RCL when desired). Since it is a critical control, cultural convention suggests that this control should be colored red or yellow.

Issues of symmetry were the next most prevalent. Researchers identified 12 instances of symmetry among all 4 OCUs. Identical controls that are symmetrically placed can lead to substitution errors. For example, an operator intending to decrease the speed selector, a rotary selector located on the right side of the OCU, may accidentally substitute the independent brake selector located on the left side of the OCU, thereby not decreasing the RCL's speed (and possibly decreasing the independent brake, if in use).

Identical controls that are adjacent to each other can also lead to substitution errors. Analyses identified five such instances of adjacency among two of the four OCUs. For example, on an OCU where the automatic brake and horn controls are similar in appearance and adjacent, a hazardous condition can arise if the RCO needs to warn somebody using the horn but accidentally operates the automatic brake instead. Shape or color coding can help reduce the likelihood of this type of error occurring.

Finally, one instance exists where a critical control was not properly protected. In such a case, accidental activation can lead to a hazardous condition. Protection against accidental activation can come in a number of forms, including physical protection (e.g., recessed or physically covered or barricaded controls), procedural protection (e.g., a button might require a press and hold for a number of seconds to activate, or the activation of a control might require another switch to be manipulated simultaneously), or modality protection (e.g., where a control will not become active unless the operation is in the correct mode, where accidental activation would not be hazardous).

3. RCL OCU Human Factors Functional Design Guidelines

The primary goal of generating a preliminary set of human factors functional design guidelines for RCL systems is to enhance RCL safety through improved OCU design (i.e., reduce the likelihood of design-induced human error). This approach is consistent with other efforts by FRA to introduce human factors to the railroad industry and is non-prescriptive in nature. The guidelines are intended to support RCL suppliers; they are not meant to be a standard.

Researchers used several criteria to support the development of the guidelines. Criteria included the following:

- The design focus should be on the OCU as the primary interface between the RCO and RCL system.
- Guidelines should be performance-oriented in order to provide guidance on what an OCU should be able to do but not how it should do it. This will provide suppliers with the flexibility to design according to their own philosophies.
- Guidelines should be written in a standard format and easily understood. For example, "The OCU shall be able to…."
- Guidelines should be consistent with other related FRA work on human-machine interface and HFE.
- Guidelines should be able to accommodate future functionality and capabilities.

3.1 RCL OCU Functional Guideline Development

The steps used to generate the functional guidelines included:

1. Articulating the expected range of RCL operating environments and users
2. Reviewing related HFE guidelines (e.g., FRA Safety Advisory 2001-01)
3. Identifying emerging technologies through discussion with several RCL SMEs
4. Identifying the major human factors issues associated with RCL OCUs
5. Identifying a set of top-level functional categories for human factors functional design guidelines
6. Generating a set of preliminary human factors functional design guidelines for each category based on consideration of the RCL operating environment and users, review of related guidelines and results of the OCU analysis, and application of human factors and RCL SME

Railroads use RCL systems in a wide range of outdoor operating environments, from extreme cold to extreme heat, from very dry air and dust to 100 percent humidity and precipitation (e.g., rain, snow). RCL systems may be used any time of day; therefore, systems are exposed to a range of ambient lighting conditions. Furthermore, the railroad classification yard can be a very noisy operating environment due to noise from locomotives, radios, coupling, and wheel-on-rail interactions. Therefore, RCL systems must be designed for a wide range of operating environments.

Multiple RCOs use a single RCL system and associated OCUs over the course of a single day. These RCOs:

- Have a range of training and operational experiences
- Have a range of educational experiences
- Come from a range of cultural backgrounds and from all parts of the United States
- Have a range of body dimensions
- Span several generations (and thus, for instance, will have different expectations of, and comfort levels with, technology)

Therefore, RCL systems must be designed to accommodate a wide range of users.

A number of existing, well-known, and comprehensive human factors design handbooks, guidelines, and design standards, such as DoD Mil-HDBK-759C (Human Engineering Design Guidelines) and DoD Mil-Std-1472F (Human Engineering) are not applicable since they are design-specific; the RCL guidelines developed in this project are written at the functional requirement level.

General design guideline and requirements reference materials that address locomotive and RCL operations, as well as remote operation of heavy equipment, can be used to support development of the human factors functional design guidelines for RCL systems. Reference sources include materials published by FRA, AAR, and several domestic and international standardization bodies, such as ANSI, ISO, and SAE International. In addition, several software user interface guideline references were reviewed to determine if any software user interface guidelines exist that may be relevant to interaction with RCL systems.

Specific reference materials used in the development of the RCL human factors functional design guidelines include the following:

- FRA Safety Advisory 2001-01 (2001).
- AAR RCL Standard S-5507 (2006).
- FRA's *Human Factors Guidelines for Locomotive Cabs* (Multer, Rudich, & Yearwood, 1998).
- FRA's human-machine interface design guidelines contained in Appendix E of the recently revised 49 CFR § 236 (2005).
- ISO Standard 15817, *Earth-Moving Machinery—Safety Requirements for Remote Operator Control* (ISO, 2005).
- European Standard EN 1889-2, *Machines for Underground Mines–Mobile Machines Working Underground–Safety, Part 2: Rail Locomotives* (European Committee for Standardization, 2003).
- Australian/New Zealand Standard 4240, *Remote Controls for Mining Equipment* (Standards Australia/Standards New Zealand, 1994).
- British Standard BS EN 50239: 2000, *Railway Applications – Radio Remote Control System of Traction Vehicle for Freight Traffic* (BSI Group, 2000).

- Nielsen's *Ten Usability Heuristics (n.d.).*
- Cornell University's *Ergonomic Guidelines for User-Interface Design (n.d.)*.

Each of these documents was reviewed to identify relevant human factors guidance or support with regard to RCL systems. Many of the RCL OCU guidelines were adopted from Multer, Rudich, and Yearwood's *Human Factors Guidelines for Locomotive Cabs* (1998), since locomotive operations and RCL operations share a number of commonalities.

3.2 Emerging RCL Technologies and Capabilities

The guidelines should be flexible enough to cover future RCL OCU functionality and capabilities. Consequently, the research team contacted and asked several RCL SMEs to discuss any emerging RCL technologies and capabilities of which they were aware through informal and formal conversations, presentations, and discussions with railroad industry and supplier representatives. The list below summarizes the emerging RCL technologies and capabilities that RCL SMEs identified. The order of the list does not represent any prioritization, nor does identification of any specific technology reflect any type of affirmation that these technologies and capabilities will actually make their way to production RCL systems. The purpose of this exercise was to simply expose guideline developers to possible enhanced features and functionality so that the guidelines that are developed will be as relevant as possible for as long as possible.

The following identifies and briefly discusses the emerging technologies:

- *Integration of RCL systems with over-the-road main track systems and operations*. One example is the integration of an RCL system with New York Air Brake's LEADER system to enhance an operator's control of the locomotive and train.
- *Integration of remote switch lining capability*. New, automated switches in railroad yards can currently be lined remotely using a wayside or body-worn keypad.
- *Remote video monitoring*. RCL operations employing remote video monitoring are currently limited to wayside fixtures; in the future, however, it is conceivable that body-worn video monitoring could be added or incorporated into an RCL system.
- *Impact detection*. Future RCL systems may be able to detect, and warn the RCO of, impacts between an RCL and another piece of on-track equipment.
- *Integration of dynamic and automatic (i.e., blended) brakes.* Future RCL systems may provide the RCO with a single brake control that combines automatic (air) and dynamic braking capabilities. The Acela power units currently implement blended braking.
- *Provision of additional feedback to the RCO*. The goal would be to provide additional cues normally provided on board a locomotive to the RCO.
- *Change in weight, size, and dimension of the OCU*. The goal would be to reduce the overall stress on the RCO's body associated with long-term use (e.g., 8-10 hours).

3.3 Human Factors Technical Issues Related to OCU Design

This section briefly discusses some of the potential human factors issues related to the design of an RCL OCU. These include situation awareness, task and information overload, trust and overreliance, inadvertent activation, and interaction with OCU training and experience. Most of these issues are not specific to RCL operations; rather, they address common issues related to the interaction between a human operator and any technological system used to carry out work.

3.3.1 Situation Awareness (SA)

A potential for a reduction in RCO SA can occur due to several possible factors: a lack of kinesthetic (feel), visual, and aural feedback; the degree of automation of the RCL system; and the number and types of tasks and responsibilities. The following discusses the specific types of SA that are relevant to RCL systems in greater detail.

Reduction in Bodily SA

Railroad yards are hostile, dynamic environments where employees, who are continuously moving about, are placed in continuous contact with moving cars, locomotives, and arriving/departing trains. It is paramount that these employees maintain a high degree of awareness of their body and its position relative to their immediate surroundings at all times while in the yard to ensure their own safety. The additional tasks and responsibilities related to RCL operation on top of those required of conventional switching operations have the potential to overwhelm or distract the RCO, thereby capturing the RCO's attention, even if only momentarily, and reducing his/her awareness of his/her surroundings.

Reduction in RCL SA

Given remote operation of an RCL and cut of cars, and the extent to which the level of automation and authority of the RCL system is conveyed (transparency) to the RCO, the RCO may not know precisely what is happening with respect to the RCL and cut of cars that he/she is controlling at any moment in time. Automation refers to the level of tasks performed by the RCL system (compared to the tasks required of the RCO), while authority refers to the extent to which the RCL system and (separately) RCO can control the RCL system. A situation where a high degree of automation exists without operator feedback can lead to unexpected or unexplained actions by the RCL (for example, an RCL may apply an emergency brake application for no apparent reason to the RCO). RCL operations can potentially introduce several specific types of reduced RCL SA (Reinach & Acton, 2006). They include:

1. *Loss of locomotive orientation awareness*. The RCO may forget, or may not know, the locomotive orientation (i.e., the particular direction the RCL is headed) due to his/her position away from the RCL and thus may initiate a movement in the wrong direction.
2. *Lack of RCL response feedback*. If an RCO is on the ground in a position where he/she cannot see or hear the RCL, he/she may not see or hear the locomotive responding to the OCU command to speed up or slow down. Communication delays between the OCU and the RCL can exacerbate this problem.

3. *Loss of movement awareness*. An RCO on the ground does not have the kinesthetic feedback provided to the engineer or RCO on board. For example, he/she may not feel dragging equipment or a derailed car, a break in the cut of cars, or even a collision. This problem is exacerbated if the RCO is positioned where he/she cannot hear or see the RCL or part of the cut of cars.

3.3.2 Task and Information Overload

The potential for task overload, and resultant loss of SA or errors, exists due to the increase in tasks and responsibilities that come with RCL operations in addition to regular switchman tasks and responsibilities. An RCO is responsible for not only his/her safety, car handling, and switching (switchman tasks), but also the control of the RCL to make the moves (RCO task). RCOs now carry out more tasks than either a locomotive engineer or switchman. These tasks may include: operating a radio; operating the OCU, including interpretation of OCU control positions, displays, and warning information; lining switches; observing the path and progress of the RCL and cut of cars; mounting, dismounting, and riding equipment; walking and staying free of rolling equipment; reading a switch list; and possibly holding a lantern or flashlight (if nighttime operation). RCOs must also consider the logistics of their switch moves, including any special handling of a car, how far into a track cars must be shoved or kicked, whether or not air needs to be bled from cars, whether and how many hand brakes must be set, and a yardmaster's requirement to get in the clear by a certain time. In remote control zones (RCZ), RCOs are additionally responsible for keeping track of who enters and exits the RCZ. As a means of trying to manage the large number of tasks, an RCO may focus exclusively on one or a few tasks and ignore all other tasks, leading to channelized attention, where the RCO ignores important information in the operating environment, resulting in a reduction in the RCO's SA. The increase in RCO tasks can also lead to operator error due to a misunderstanding, loss/lack of attention, or distraction brought on by the high number of task demands.

3.3.3 Trust and Overreliance on the System

As with any type of technological automation, the potential exists for an operator to overrely on the technology. This can result in a loss of SA, where an operator can become complacent and not remain vigilant with respect to the operation of the RCL and his/her surroundings. Conversely, if the system proves unreliable, an operator may not trust the system to carry out functions it has been designed to carry out. This can lead to increased workload, distraction, and possible loss of SA if the operator focuses too much attention on the technology and too little attention on his/her surroundings and RCL operation.

3.3.4 Inadvertent Activation

Both Reinach and Acton (2006) and Gamst and Gavalla (2005) have observed that inadvertent, or accidental, activation of OCU controls can be a nuisance in RCL operations but could be a hazard under the wrong set of circumstances. OCU controls, displays, and the physical form of the OCU all play a major role in preventing inadvertent activation. As such, careful consideration should be paid to the OCU's design and its controls and displays to minimize the risk of inadvertent activation and maximize safety.

3.3.5 Interaction with RCO Training and Experience

The combination of increases in new hires with no prior railroad experience (especially switching experience) and reported or observed inadequacies in RCO training and preparation (Reinach & Acton, 2006; Reinach & Viale, 2006) can contribute to RCO errors and accidents/incidents due to a lack of knowledge, familiarity, and/or understanding of RCL operations and the OCU (as well as, more generally, the yard layout and switching). This combination is of concern, for example, in a situation where an inexperienced RCO focuses his/her attention on a feature of the OCU at the expense of his/her bodily SA or awareness of the RCL and surroundings. Thus, incorporation of human factors principles is critical to support inexperienced RCOs.

3.4 RCL OCU Human Factors Functional Design Guidelines

Since the guidelines are intended to support RCL designers and are not specific requirements, the language used to write the guidelines is consistent with this voluntary spirit. Consequently, guidelines use the should modal verb (a.k.a. helping verb or auxiliary verb) rather than the shall modal verb often used in requirements specifications. For example, a guideline may read, "The OCU controls and displays should be visible to the user under all ambient lighting conditions." According to Kar and Bailey (1996), well-written requirements should also be: concise, implementation-free, complete, consistent, unambiguous, verifiable, and written using standard constructs. Regarding standard constructs, most of the guidelines take one of the following three forms:

1. The OCU should….
2. The design of the OCU should…
3. <Specific feature or capability> should…

Guidelines address several RCL functions, including initial setup, locomotive control, OCU displays, safety features, and emerging technologies. Each guideline addresses one or more of these RCL functions.

Guidelines have the following seven general categories: general design, general function, feedback, labels, use of color, visual displays and indicators, and auditory displays and alarms. Each of the four OCUs that the researchers analyzed exhibited designs that were consistent with at least several of the guidelines. Researchers, however, did not perform an analysis of the precise extent to which OCUs conformed to the guidelines. Researchers identified a total of 51 guidelines. Many of the RCL OCU guidelines were adopted from Multer, Rudich, and Yearwood's *Human Factors Guidelines for Locomotive Cabs* (1998) since locomotive operations and RCL operations share a number of commonalities.

3.4.1 General Design

General design guidelines include top-level suggestions that address the overall design of the OCU. Some are quite broad in nature, while many others address the physical properties or locations of controls and displays.

- The OCU design should be consistent with recommended design guidelines provided in Section A of FRA's 2001 Safety Advisory on recommended minimal guidelines for the operation of RCLs (FRA, 2001) and design requirements presented in Section 4.1 of AAR's Remote Control Locomotives Standard, S-5507 (AAR, 2006).[2] A significant amount of overlap exists between these two documents; where discrepancies arise, it is recommended that the more conservative guideline or requirement prevail unless overwhelming operational or safety reasons to implement the other guideline/requirement exist.

- Controls and visual displays and indications should be visible under all ambient lighting and weather conditions (from bright sunshine and glare to total darkness).
    - RCOs should be able to adjust both the contrast and brightness of OCU displays to accommodate the wide range of ambient lighting conditions.
- Controls and displays should be clearly labeled, clearly identifiable, and clearly distinguishable from other controls and displays.
    - Controls with similar functions or purposes should be positioned near each other.
    - The OCU should use shape, and color to a less extent, to distinguish controls.
- Displays should be located as close as possible to the controls for which they provide feedback.
- The OCU should be designed to facilitate high stimulus-response compatibility.
- The OCU should be designed to minimize the amount of heads-down time where an RCO is looking at the OCU.
- The OCU should be designed to protect against inadvertent activation of controls, caused by reaching in to make air hoses, lining switches, climbing ladders, and tying hand brakes, or by bumping one control while trying to activate an adjacent one.
- The OCU should be designed to minimize the number of steps necessary to effect a desired change.
- The OCU should be designed to avoid, or at least minimize, distracting the RCO.
- The OCU should be designed to avoid producing a state of operator information overload.
- The OCU should be designed to support operator SA at all times.
- The OCU should be designed to rest comfortably on an RCO's body and should be as lightweight as possible to ensure comfort and fit over extended periods of use.
- OCU control actuation should be natural for the RCO.

3.4.2 General Function

Guidelines in this section address general OCU functionality.

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[2] FRA and AAR refer to the RCL OCU as a remote control transmitter.

- The OCU should enable an RCO to recover from accidental activation of a control (a.k.a. error recovery or reversible action) whenever practical.
- System errors and failures should be easily recoverable.
- The OCU should be capable of displaying programmable running time and/or distance traveled information.
- The OCU should be capable of displaying the battery charge status.
- The OCU should be equipped with an emergency stop control.

3.4.3 Feedback

These guidelines address the need for and importance of providing feedback to the RCO.

- Each control actuation or other RCO input should produce a perceptible response output.
- The OCU should provide feedback on RCO-requested actions, the state of the RCL system, and the state of the RCL, as close in time as possible with the requested action, change in RCL system state, or change in RCL state.
    - OCU feedback should distinguish between a delay in system response to a user-requested action and the system that is awaiting an RCO command.
- The nature of system failures and errors should be clearly conveyed.
- Feedback should clearly indicate the corrective action to take when a system failure or error occurs.

3.4.4 Labels

Guidelines in this section address OCU labels for various controls and displays.

- Labels should be able to withstand damage and wear under the full range of expected operating conditions.
- Labels should use words and abbreviations that are familiar to the RCO.
- Labels should use concise wording.
- Labels should be located near controls.
- Labels should be added to enhance comprehension or distinguish sets of controls.

3.4.5 Use of Color

These guidelines discuss the appropriate use of color for OCU controls and displays. The first three guidelines are specific examples of a more general rule of thumb, which is that colors should be generally consistent with cultural and domain norms.

- Safety-critical controls and displays should be color coded red (for the most safety-critical controls/displays, such as equipment failures) or yellow/amber (for less critical controls/displays, such as warnings).

- Permissive controls and displays should be color coded green.
- Neutral controls and displays (including indicator lights and non-critical visual messages) should be color coded something other than red, yellow/amber, or green.
- Use of colors in displays should be limited.

3.4.6 Visual Displays and Indicators

Guidelines in this section address the design of visual displays, including indicator lights and clusters.

- Alphanumeric messages, including error messages, should:
    - Be specific (i.e., task-oriented).
    - Employ standard, user-centered words and messages.
    - Use complete words where feasible.
    - Employ plain, concise, and constructive language that RCOs will understand.
    - Avoid words with multiple meanings.
    - Avoid the use of all uppercase letters except for single words and short phrases that must draw an RCO's attention. To be effective, limit the use of all upper case. Mixed case is preferable to increase comprehension.
- Where abbreviations are necessary, the OCU should employ simple, familiar, and easy-to-understand abbreviation forms.
- OCUs should employ common abbreviations and avoid abbreviations that are ambiguous or that can be misinterpreted.
- Icons, symbols, and graphics should be simple, easy to recognize, and representative of the nature for which they are used.
- Alphanumeric messages should support recognition memory over recall memory to minimize the load on the RCO's memory.
- Displays should use as little color as possible, and only when necessary, to improve comprehension and distinguishability.
- The OCU should be designed to enable an RCO to retrieve critical alphanumeric messages in case he/she needs to recall information from a recent past message.
- Visual displays should avoid the following color contrast combinations: red/blue, red/green, blue/yellow, and green/blue.
- High frequency flashing visual displays and indicator lights should be reserved to communicate urgent or critical information.

3.4.7 Auditory Displays and Alarms

Guidelines in this section address the design of auditory displays and alarms. In general, alarms include nonverbal warnings and alerts, although alarms can include speech messages. Alarms warn an RCO of a time-sensitive or safety-critical situation that requires RCO action or attention.

- Auditory displays and alarms should be loud enough to be detected above the ambient sound level but should not startle the RCO or disrupt the appropriate response. Loudness of the display or alarm should be consistent with the importance of the message.
- When speech is employed, natural speech displays should be used rather than synthetic speech to increase comprehension.
- Alarms should be used to present high-priority, critical, and urgent information (e.g., in cases where an RCO must respond immediately to avoid a hazard).
- The OCU should be designed to minimize the number of different alarms.
- Alarms should avoid using sounds that may be confused with noises an RCO would routinely be exposed to in the railroad operating environment (e.g., air brake discharges, wheel-rail screeching, sanding).
- Alarms should be used under the following conditions:
    - The message is simple and short.
    - The message does not need to be referred to later.
    - The visual channel is overtaxed.
    - The message relates to events in time.
- Alarms should convey the level of danger or risk associated with the warning.
- Alarms should convey the urgency or priority of a response so that the RCO can allocate his/her attention appropriately, especially when multiple auditory alarms are displayed.
- RCOs should be able to acknowledge and shut off non-critical alarms.
- Alarms should be sounded until the condition is relieved or the operator acknowledges.
- When alarms are presented both visually and aurally, RCOs should be able to shut off the auditory alarm without deleting the accompanying visual message.

4. Key Findings and Next Steps

This section contains a brief recapitulation of the key findings from the study and identifies the next steps in developing a set of industry-accepted human factors functional design guidelines for RCL systems.

4.1 Key Findings

Key findings from the study include the following:

- Analyses of four RCL OCUs identified some potential human factors design issues. HCTOOL, however, required substantial human factors and RCL SMEs to validate and interpret the analysis results due to shortcomings in the tool and redundancies in the tool's output.
- Of 13 possible types of human factors design issues that were analyzed, researchers found 5 among the 4 OCUs. These included: instances of inappropriate use of color in displays, instances of poor color choices for critical controls, symmetry issues, adjacency issues, and one instance of a critical control not being protected. Table 2 presents a summary of the OCU analysis findings.

Table 2. OCU analysis summary

Human Factors Design Issue	Number of Instances Found Among 4 OCUs
Inappropriate use of color in displays	**16**
Poor color choices for critical controls	**15**
Symmetry	**12**
Adjacency	**5**
Critical controls not protected	**1**
Total	**49**

- Based on conversations with RCL SMEs, emerging technologies and designs that may find their way into future RCL systems include: integration of RCL systems with over-the-road main track systems and operations; integration of remote switch lining capability; remote video monitoring; impact detection; integration of dynamic and automatic (i.e., blended) brakes; provision of additional feedback to the RCO; and a change in weight, size, and dimension of the OCU.
- Human factors technical issues that affect the design of the RCL OCU include: SA, task and information overload, trust and overreliance, inadvertent activation, and interaction with OCU training and experience.
- The research team identified and organized a total of 51 human factors functional design guidelines into the following 7 categories: general design, general function, feedback, labels, use of color, visual displays and indicators, and auditory displays and alarms.

4.2 Next Steps

Researchers identified two future projects to help promote full development and adoption of RCL human factors functional design guidelines. These two projects flow naturally from the work described in this report. The following discusses these projects.

4.2.1 Validate the Results of the OCU Analysis with RCL Suppliers

Use of the automated HCTOOL software was a first step in assessing RCL OCUs for their conformity to generally accepted human factors user-centered design principles. HCTOOL, however, is experimental, and results required a substantial amount of validation and interpretation to ensure they were accurate. Given the experimental status of the software and the need for significant interpretation and validation, the researchers recommend that the results of each analysis be reviewed with the RCL suppliers whose OCUs were analyzed. Such review would ensure that analysts correctly interpreted and understood OCU and RCL functionality, and it would provide an independent validation of the analyses. This exercise would also provide an informal format in which to discuss the meaning of the results of the OCU analysis and possible adoption of the human factors functional design guidelines.

4.2.2 Further Develop the RCL OCU Human Factors Functional Design Guidelines

The natural next step in this research program is to advance the guidelines beyond their preliminary stage to a more mature, authoritative set of industry-adoptable guidelines. To this end, the research team suggests the following steps:

- Conduct a more thorough literature review to substantiate the guidelines.
- Document the rationale and reference sources for each guideline.
- Provide examples of the implementation or interpretation of each guideline.

This list is not meant to be exhaustive; rather, it is a starting point to help facilitate advancing the preliminary guidelines to a more finished product.

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Appendix A.
Analysis of U.S. and Canadian RCL Accidents/Incidents

One of the first steps taken in the generation of human factors functional design guidelines for RCL systems was to analyze railroad accidents/incidents involving RCL operations to determine whether the design of the OCU (as the primary interface between the OCU and RCL system) had a role in contributing to known accidents/incidents. The analysis focused on U.S. and Canadian accident/incident databases maintained by FRA and Transportation Safety Board (TSB) Canada, respectively. Due to methodological limitations associated with original data collection and structural limitations to the accident/incident databases, no conclusive information existed in either the U.S. or Canadian databases about the role of the OCU in contributing to accidents/incidents. Appendix A describes this effort in greater detail.

A.1 Introduction to U.S. and Canadian Rail Accident and Incident Reporting Requirements

Railroads operating in the United States must report accidents and incidents (including injuries and illnesses) that meet FRA reporting requirements. These requirements are described in detail in FRA's Guide to Preparing Accident/Incident Reports (FRA, 2003) and codified in 49 CFR § 225. U.S. railroads must provide a host of information to FRA regarding reportable accidents and incidents, including predominantly descriptive information about the event and resultant injuries and property damage. Railroads must also identify an accident or incident cause as part of their reporting requirements. Currently, the primary reporting criterion for rail accidents is property damage that meets or exceeds $7,700. The reporting criteria for rail injuries (and illnesses) are based on incident severity. Typically, any injury that requires medical attention beyond first aid is reportable. FRA's Guide to Preparing Accident/Incident Reports provides more specific definitions and reporting criteria for rail accidents and incidents.

Railroads operating in Canada must follow a separate set of reporting requirements and standards. TSB Canada, the independent Federal safety agency responsible for rail accident and incident data collection in Canada, classifies five different levels (classes) of Canadian accident/incident occurrences. Class 5 occurrences are accidents and incidents that meet minimal reporting requirements, specified in the Canadian TSB Regulations (1992). These are most analogous to the FRA reportable accidents and incidents in the United States that are described above. Similar to the U.S. reporting requirements, railroads operating in Canada must provide data and information pertaining to accidents and incidents that occur in Canada to TSB Canada.[3] Although a Canadian railroad may elect to provide as much information as it wants to TSB Canada, it is required to provide only the following minimal information on reportable (i.e., Class 5 occurrence) rail accidents and incidents (Transportation Safety Board Regulations, 1992):

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[3] A Class 4 occurrence is a safety issue investigation, also similar to National Transportation Safety Board (NTSB) safety studies. Class 2 and 3 occurrences are individual occurrence investigations, similar to U.S. NTSB accident investigations. Finally, a Class 1 occurrence is a public inquiry in which one or more accidents or incidents is explored in significant detail to increase public safety.

- Train number and direction
- Names of railway company and track operator
- Crewmember names
- Date and time of accident or incident
- Accident location (including milepost and track designation, such as main track or yard)
- Number of crewmembers and passengers injured (including fatal)
- Description of the accident or incident and resulting damage to equipment, track, property, and environment
- Summary description of dangerous goods (i.e., Hazmat) involved in accident/incident
- Anticipated time of arrival of wreck-clearing equipment (if applicable)
- Name, location, and title of individual making the report

Thus, railroads operating in Canada are required to provide to Canadian authorities only a subset of the data that railroads operating in the United States are required to report to U.S. authorities. A unique aspect of the TSB Canada data collection system is that TSB Canada may elect to collect additional information about a particular Class 5 accident or incident, either directly from the railroad or themselves.

U.S. and Canadian rail accident and incident data contain very little information on accident/incident contributing factors. As noted above, U.S. railroads must identify a cause for each reportable accident/incident. TSB Canada does not require railroads to identify a specific cause.[4] Typically, however, these causes, which are in the form of codes a reporting U.S. railroad officer must select when completing an accident/incident report, are brief, descriptive statements of what happened, not why. An example of a human factors train accident cause code is, "Shoving movement, man at or on leading end of movement, failure to control."

The U.S. and Canadian rail accident and incident databases, however, include narrative fields that a railroad officer can use to provide additional details about the accident/incident. These narrative fields typically contain additional descriptive information about the accident, such as a brief scenario description, identifying information such as train IDs, information about the involvement of Hazmat, and other similar circumstances. Analysis focused on these narratives to identify any information that was relevant to human error as a result of the RCL OCU design.

A.2 RCL Accident/Incident Analyses

The goal of this task was to analyze 2 years (yr) of U.S. RCL accident and incident data (2004-2005) and 5 yr of Canadian RCL accident and incident data (2001-2005) to determine the extent to which the RCO's interaction with the OCU, loss of SA, loss of critical task cues, inadequate training, and/or inadequate practices and procedures contributed to RCL accidents and incidents (employee-on-duty injuries). RCL operations were introduced in Canada earlier than in the United States, thus the Canadians began to track any accidents/incidents earlier. To begin,

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[4] A number of optional cause code fields exist that can be completed by TSB Canada investigators if TSB Canada elects to collect additional information on a particular Class 5 rail accident.

operationally defining many of these categories, such as loss of SA and loss of critical task cues, proved very difficult. Definitions tended to be descriptive but not discriminatory.

Analysis depended primarily on review of accident/incident narratives, where railroad reporting officers provide supplemental information about accident/incident origins. Based on the information provided in the narratives, it simply was not possible to say with certainty that any of the factors discussed in the narrative, singly or in combination, addressed the design of the system and contributed to a particular accident. With few exceptions, the information contained in the narrative fields simply provided further information regarding what happened, not why it happened. For instance, in the case where information contained in a (hypothetical) accident narrative explains that an RCO pressed the wrong button on the box, it is not possible to say with certainty that this was due to the design of the box, since it is equally possible that an attentional failure (e.g., a distraction) may have led to the errant button press.

This analytical approach was limited since it narrowly focused on seeking out evidence of specific contributing factors (e.g., loss of SA). To see if anything could be gleaned from the U.S. accident and incident narratives more generally, researchers conducted a second preliminary analysis. Researchers first reviewed the RCL accident data analysis included in FRA's RCL Report to Congress (2006), and then they selected the following top three human factor train accident cause codes associated with the largest number of RCL accidents:

- H306-Shoving movement, absence of man on or at leading end of movement
- H307-Shoving movement, man at or on leading end of movement, failure to control
- H702-Switch improperly lined

Researchers identified all RCL accidents between 2004 and 2005 with H306, H307, and H702 train accident cause codes and reviewed the narratives for each accident to determine if it was feasible to clearly identify any human factors contributing factors (e.g., fatigue, communications, or distraction).

Out of the 548 RCL accidents between 2004 and 2005, 240 (44 percent) were associated with H306, H307, and H702 train accident cause codes. Some of the narratives suggest certain human factor issues may have contributed to the particular accident. These include the following (possible human factor issues are identified in brackets following the summarized item taken from the narrative):

- Failed to communicate car count [Poor communication, attentional failure]
- Failed to notice equipment foul [Attentional failure, loss of SA]
- Forgot direction of engine [Memory failure, loss of SA, poor design of technology]
- Did not catch control of OCU correctly; crewmember thought he had control [Attentional failure, poor design of technology]
- Put [reverser] in wrong direction/selected wrong direction [Attentional failure, loss of SA, poor design of technology]
- Put speed selector in wrong setting/selected wrong speed [Attentional failure, loss of SA, poor design of technology]
- Fell asleep [Fatigue]

- Thought yardmaster was protecting [Poor communication]
- Forgot to line switch [Memory failure, loss of SA]
- Lined wrong switch [Attentional failure, loss of SA]

For many of the accidents, multiple contributing human factor issues (e.g., attention failure, loss of SA, fatigue) may have played a role in the accident based on the information provided in the narratives. It was not possible from the information provided, however, to say with certainty that a specific human factor issue contributed to any particular accident. In fact, often at least two possible human factor issues exist that could explain some portion of the narrative information, as illustrated in the bulleted items above. Narratives, thus, did not provide sufficient information to determine whether or not specific human factors issues contributed to particular accidents/incidents.

As a result, review of U.S. and Canadian RCL accidents/incidents proved inconclusive about the possible role of the OCU design in accidents/incidents because these databases currently do not support such analysis.

Appendix B.
An Introduction to HSI in the U.S. Railroad Industry

Appendix B presents an introduction to HSI. It contains a brief executive summary followed by a discussion of HSI and how HSI can benefit the U.S. railroad industry.[5]

B.1 Executive Summary

HSI is a systematic, organization-wide approach to implementing new technologies and modernizing existing systems. It is a combination of managerial philosophy, methods, techniques, and tools designed to emphasize the central role and importance of users in organizational processes or technologies during the acquisition process. This approach optimizes the safety and efficiency of these systems through the consideration of all of a system's elements. Traditional approaches to technological implementation focus on mechanical, hardware, and software design challenges. Often little attention is paid to the user and his/her capabilities and limitations. Developers assume that the introduction of the technology will be automatically acceptable to the users and improve job performance. This does not always hold true.

The safety and reliability of new and modernized technologies and systems ultimately depend on their interaction with users (i.e., operators and maintainers). Even the most sophisticated technologies, when designed and implemented without proper consideration of user needs and requirements, may not achieve optimal system performance because of mismatches between the technology and human operator limitations or capabilities. To help achieve optimal overall system success, the developers should view the human operator as a central part of the system. Careful evaluation of an operator's interaction with a system during its initial design eliminates potential mismatches downstream during the system's implementation and operation.

FRA is interested in introducing HSI to the railroad industry to help railroads further improve the safety and efficiency of their operations. An HSI approach to railroad technology acquisition and implementation can increase user acceptance of the technology, increase usability of the technology, and increase the likelihood of successful technology deployment. Investing in a systems approach to technology acquisition and modernization can provide a return on investment that is both tangible (e.g., cost savings) and intangible (e.g., improved labor relations).

Over time, U.S. railroads have incorporated individual elements of an HSI approach (e.g., user testing, consideration of training requirements) into the acquisition of various technological systems. The purpose of this paper is to provide an introduction of HSI concepts to the U.S. railroad industry and stimulate discussion of an HSI framework that can support railroads' technology acquisition processes*,* since it is in these processes that railroads have the ability to economically and efficiently specify system requirements and most successfully implement technology.

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[5] This appendix is based on a white paper prepared for FRA under separate cover. The white paper can be found on FRA's Web site at http://www.fra.dot.gov/us/content/1716. Mr. Michael Jones, FRA, assisted in preparing the white paper.

The U.S. military is currently the largest HSI practitioner in the United States. The U.S. Army articulates the following seven topical areas where the impact of a new technology must be considered before the technology is approved, acquired, and deployed (or modernized):

1. *Manpower*. The manpower domain includes consideration of the staff required to operate, maintain, sustain, and train for the technology or system under consideration.
2. *Personnel*. This domain focuses on the knowledge, skills, abilities, and other characteristics (KSAOs) necessary to train for, operate, maintain, and sustain the new or modernized technology or system.
3. *Training*. The training domain addresses the instructional requirements crucial to instill the KSAOs that are necessary to operate, maintain, and sustain the new or modernized technology or system.
4. *Human factors engineering*. Human factors engineering focuses on designing human system interfaces to optimize user performance and reduce the likelihood of user errors.
5. *System safety*. System safety addresses the potential for new or modernized systems to contribute to, or cause, errors or failures that can lead to accidents.
6. *Health hazards*. The health hazards domain focuses on mitigating the potential for regular and routine use of the system to result in bodily harm—that is, injury, illness, and death, as well as reduced system performance that may result from bodily harm.
7. *Survivability*. This domain addresses the need to increase the likelihood that soldiers survive attacks of various natures, including fratricide. In the context of railroad operations, this domain might focus on designing systems to improve occupant protection and survivability.

Advantages of HSI include the potential to:

- Increase U.S. railroad safety.
- Improve operator performance and operational efficiency.
- Increase user acceptance.
- Reduce training time and costs.
- Reduce the likelihood of, and costs associated with, system upgrades and midcourse design changes.
- Reduce system lifecycle costs.

To gain the full benefit of HSI and its integrated systems approach to technology and modernization programs, railroads, including management, labor, and trade associations, can:

- Allocate sufficient monetary and staff resources to develop an HSI program to support system acquisitions and modernizations.
- Develop an overarching HSI policy and process that govern how HSI will be applied to new system or technology acquisitions and modernization programs.
- Develop a human systems integration plan (HSIP) for each new or modernization program.

- Appoint a human factors champion to each program.
- Incorporate human factors engineering data collection and analysis techniques to understand users, tasks, and the operational environment.
- Use quantifiable and documented human factors engineering data to guide and support HSI design specifications and requirements.
- Use HSI design specifications and requirements to support the statement of work and the specific tasks that a technology or system supplier must complete when developing the technology or system to be acquired.

In support of railroads' effort to apply an HSI approach to technology upgrades and modernization programs, railroad suppliers can:

- Employ and use human factors professionals on railroad programs to ensure that user capabilities, limitations, and requirements are considered and included in system designs.
- Involve human factors specialists at the earliest stages of, and throughout, system design and development.
- Use human factors data collection and analysis techniques to collect quantitative and qualitative user performance, preference, and acceptance data when developing new or modernized systems. Start with fundamental baseline data, such as results from task and job analyses.
- Ensure that design decisions for new and modernized systems include human factors and human performance data, to the extent possible. Sources of data may be internal usability tests or published information, such as anthropometric data. One approach to ensuring the use of human factors and human performance data is for suppliers to develop an internal quality standard that requires the use of these data as part of their design and development process.
- Ensure that designers have a mastery of the subject domain for which the new technology or system will be used. This might involve utilizing in-house SMEs, hiring an SME consultant, or including railroad SMEs as part of a design advisory group.
- Ensure that the system being developed satisfies all of the contracting railroad's human-centered design requirements and specifications.

The following material presents a more thorough introduction to HSI, briefly discusses other industries that have used HSI in the United States and abroad, provides examples where HSI can be applied in the U.S. railroad industry, and discusses the advantages of HSI implementation. The appendix concludes with some HSI suggestions that the railroad industry can begin to adopt.

B.2 Introduction

HSI is a systematic, organization-wide approach to implementing new technologies and modernizing existing systems. It is a combination of managerial philosophy, methods, techniques, and tools designed to emphasize the central role and importance of users in organizational processes or technologies during the acquisition process. This approach optimizes the safety and efficiency of these systems through the consideration of all of a system's elements. Traditional approaches to technological implementation focus on mechanical, hardware, and software design challenges. Often little attention is paid to the user and his/her capabilities and limitations. Rather, the developers assume that introduction of the technology will automatically be acceptable to the users and will improve job performance. This does not always hold true.

The safety and reliability of new and modernized technologies and systems ultimately depend on their interaction with users (i.e., operators and maintainers). Even the most sophisticated technologies, when designed and implemented without proper consideration of user needs and requirements, may not achieve optimal system performance because of mismatches between the technology and human operator limitations or capabilities. To help achieve optimal overall system success, the human operator should be viewed as a central part of the system. Careful evaluation of an operator's interaction with a system during its initial design eliminates potential mismatches downstream during the system's implementation and operation.

FRA is interested in introducing HSI to the railroad industry to help the railroads further improve the safety and efficiency of their operations. An HSI approach to railroad technology acquisition and implementation can increase user acceptance of the technology, increase usability of the technology, and increase the likelihood of successful technology deployment. Investing in a systems approach to technology acquisition and modernization can provide a return on investment that is both tangible (e.g., cost savings) and intangible (e.g., improved labor relations).

Over time, U.S. railroads have incorporated individual elements of an HSI approach (e.g., user testing, consideration of training requirements) into the acquisition of various technological systems. The purpose of this paper is to provide an introduction of HSI concepts to the U.S. railroad industry and stimulate discussion of an HSI framework that can support railroads' technology acquisition processes, since it is in these processes that railroads have the ability to economically and efficiently specify system requirements and most successfully implement technology. The intended audience is railroad executives, senior-level managers, acquisition specialists, and any others who have a role in specifying, approving, and/or acquiring railroad systems and technologies.

This paper has several sections. Sections 2 and 3 introduce the concept of HSI and discuss an array of current HSI applications, including extensive use in the U.S. military and U.K. rail industry. Section 4 discusses a number of opportunities where HSI principles, methods, and techniques can be applied in the U.S. railroad industry, either as new technologies are introduced or as modernization programs are initiated. Section 5 discusses the advantages of incorporating an HSI approach in the acquisition or modernization of railroad technologies and systems. Section 6 discusses next steps that the railroad industry—carriers, labor, and suppliers—can take to begin incorporating HSI into their system acquisition and modernization programs. Lastly, Section 7 includes a list of references used in the preparation of this paper.

B.3 What is HSI?

HSI is a systematic, organization-wide approach to implementing new technologies and modernizing existing systems. It is a combination of managerial philosophy, methods, techniques, and tools designed to emphasize the central role and importance of users in organizational processes or technologies during the acquisition process. This approach optimizes the safety and efficiency of these systems through the consideration of all of a system's elements. In essence, HSI integrates organizations, technology, and people (Booher, 2003). HSI techniques and processes can be used to address the acquisition of one small device or as an entirely new way of organizing work tasks in an organization.

The U.S. military is currently the largest HSI practitioner in the United States. The U.S. Army's Manpower and Personnel Integration (MANPRINT) technical and management program, created in 1986, is perhaps the most well-known HSI program. The primary objective of MANPRINT is "…to place the human element…on equal footing with other design criteria such as hardware and software" (MANPRINT Handbook, 2005; p. 1). According to Booher (2003, p. 3), "The most unique aspect of the program was effective integration of human factors into the mainstream of system definition, development, and deployment." MANPRINT articulates seven topical areas where the impact of a new technology must be considered before the technology is approved, acquired, and deployed (or modernized). The seven topical areas are the following:

1. *Manpower*. The manpower domain includes consideration of the staff required to operate, maintain, sustain, and train for the technology or system under consideration. These requirements are to be considered under all operating conditions and within current and/or proposed staffing levels. For example, if an organization has established a particular staffing limit, then this staffing level may impact the number of staff available to operate and maintain the new equipment. This, in turn, will impact the equipment's design (specification) to ensure that adequate staff will be available to operate and maintain the equipment once it has been deployed.

2. *Personnel*. This domain focuses on the KSAOs necessary to train for, operate, maintain, and sustain the new or modernized technology or system. The manpower and personnel domains are closely related; manpower addresses staffing levels while personnel addresses the KSAOs required of these staff. This domain also includes many aspects of an organization's approach to talent management—how to best recruit, place, and retain its workforce.

3. *Training*. The training domain addresses the instructional requirements crucial to instill the KSAOs that are necessary to operate, maintain, and sustain the new or modernized technology or system. As technologies are introduced or modernized, tasks change, job requirements are altered, new positions may be introduced, and functions are added and removed. Consequently, it is critical to ensure that those who will operate, maintain, and otherwise support the new or modernized technology have the requisite job skills and knowledge to effectively and safely interact with the new or modernized technology or system. The total training impact on individuals and the organization should be considered. This includes technical and methodological considerations (i.e., how to train), as well as the cost of this training.

4. *Human factors engineering*. Human factors engineering focuses on designing human system interfaces to optimize user performance and reduce the likelihood of user errors. This is accomplished through designs that are compatible with user capabilities and limitations. User populations include operators, maintainers, and trainers.

5. *System safety*. System safety addresses the potential for new or modernized systems to contribute to, or cause, errors or failures that can lead to accidents. The goal is to minimize the likelihood of accidents and injuries through careful evaluation and mitigation of potential system failures and their harmful outcomes. Risk assessment

techniques can be used to identify potential system safety problems; design specifications can then be developed to guard against such problems.

6. *Health hazards*. The health hazards domain focuses on mitigating the potential for regular and routine use of the system to result in bodily harm—that is, injury, illness, and death, as well as reduced system performance that may result from bodily harm. Health hazard assessments can be used or required early in the system design process to first identify and then eliminate or mitigate potential problems related to harmful exposure to vibration, noise, ambient temperature, and various Hazmat substances.
7. *Survivability*. This domain addresses the need to increase the likelihood that soldiers survive attacks of various natures, including fratricide. In the context of railroad operations, this domain might focus on designing systems to improve occupant protection (e.g., improved cab seat designs) and survivability (e.g., new emergency egress options, automatic collision notification systems).

Although each MANPRINT domain is defined separately, in practice these domains are often interrelated. For example, manpower, personnel, and training are all highly interrelated, as are the system safety and health hazards domains.

The U.S. Department of Defense (DoD) has recently adopted HSI into system acquisitions for all branches of the military. The DoD *Defense Acquisition System* cuts across all military branches and includes two policy documents (5000.1 Directive and 5000.2 Instruction) and a guidance document (Defense Acquisition Guidebook; a compilation of best practices). The guidebook contains a full chapter devoted to HSI in the acquisition process. Each branch of the military is responsible for implementing its own HSI program, such as that of the U.S. Army's MANPRINT program. The U.S. Navy and Air Force each have their own HSI program as well. The U.S. Navy HSI program is called SEAPRINT and is based on MANPRINT. SEAPRINT is currently being used to modernize Naval ships and aviation (APA, 2005). DoD has also put together the Human Systems Integration Information Analysis Center, an in-house HSI reference source that can be used to support the HSI efforts of the entire DoD.

The U.S. Air Force has observed that HSI pays off in terms of obtaining more user-friendly equipment and facilitating successful field deployment: "Users will have confidence in the equipment, no redesign [is] necessary, no unexpected training, maintenance or supply problems [are encountered]; and [the system has] reduced lifecycle costs" (Lipscomb & Young, n.d.; slide 11).

The U.K. Ministry of Defense (MOD) and Canadian armed forces (Defence Research and Development Canada) also incorporate HSI (HSI is referred to as human factors integration (HFI) in the United Kingdom) into their system acquisition processes. The U.K. MOD has six HFI domains:

1. Human factors engineering
2. Training
3. Manpower
4. Personnel

5. (System) Safety
6. Health hazards

The Canadian armed forces have identified five HSI domains:

1. Human factors
2. Training
3. Personnel
4. Health hazards
5. System safety

Although the number of HSI domains and their terminology may vary, the overall HSI content remains the same across institutions.

HSI is also used by other U.S. government agencies that are responsible for significant mission and safety-critical technology acquisitions or that have regulatory responsibilities over industries that make significant mission and safety-critical technology acquisitions. For example, the Federal Aviation Administration (FAA) produced the *Human Factors Design Standard* in 2003 to serve as a reference for use in FAA system acquisitions. The Department of Energy (DOE) has also focused on HSI issues. DOE's Brookhaven National Labs, for example, has an HSI research program that is exploring HSI issues within the energy sector. In particular, Brookhaven scientists and engineers are looking at control room design and development and advanced alarm designs.

It is not just government agencies that have incorporated HSI into their acquisition process. The U.K. and European rail industries have made significant strides in incorporating HSI methods and tools into their technology acquisition processes. In the United Kingdom, for instance, as a result of changes to a significant London Underground railroad extension project (the Jubilee Line Extension), the regulatory agency providing government oversight identified a number of training, operability, and system reliability concerns. One such example was the development of an alarm list for an information system that overloaded operators (Lucas, 2004). These changes threatened both the safety of the line and the ability to complete the project. To rectify these problems, an interdisciplinary group from London Underground was organized and matched with a group of human factors experts to address and rectify these problems. Although successful, this midcourse change in project management and oversight was costly.

To prevent similar occurrences from happening on future projects, London Underground made a number of changes to its rail systems engineering processes. Most notably, London Underground produced an HSI standard, *HFI Standard E1035*, to ensure proper and timely integration of human factors principles and methods into the design and development of all future London Underground railway control systems. A manual of best practices was also produced to accompany the standard. The London Underground standard identifies the following areas where human factors are considered integral to systems development:

- Operability of equipment
- Physical design of equipment
- Functional safety and system security

- Staffing and training development
- Procedures and staff organization

The London Underground HFI standard contains the following major sections:

1. Responsibilities
2. Project organization
3. User representation
4. Operational concept
5. Human factors integration plan

The first three sections are administrative and address how London Underground should interact with suppliers. The fourth section places the onus on London Underground to specify how a system is to be used (i.e., concept of operations). The fifth section is a requirement for suppliers to plan for how they will integrate human factors into their system development.

Network Rail's (formerly Railtrack) *Thameslink 2000* program provides another example of how HSI can be applied to railroad system design and development. Network Rail, which maintains and operates the U.K. rail infrastructure, undertook a major rail infrastructure expansion project to expand capacity and improve service. As part of this project, the former Railtrack created a human factors operability group that was responsible for HSI. The group had three primary roles: define user requirements, ensure due process, and approve the work. The group developed an HSI strategy and created a human factors database to monitor and track human factors issues that were identified during the project. It also required each external work contractor to develop a human factors work plan that identified how human factors issues would be addressed and employ or engage human factors professionals to support their work.

The U.K. Office of Rail Regulation (ORR), which is responsible for economic and safety regulations in the U.K. rail industry, also recognizes the importance of HSI within railroad development projects. An online ORR paper entitled, *Human Factors–Human Factors Integration* (ORR, n.d.), provides support and guidance to the U.K. rail industry on the value and critical features of HSI within railroad projects. ORR identifies the following three categories through which human factors can impact the safety and health of rail operators, maintainers, and users:

- Job: Tasks, workload, environment, displays and controls, and procedures
- Individual: Competence, skills, personality, attitudes, and risk perception
- Organization: Culture, leadership, resources, work patterns, and communications

According to the online ORR paper:

> Human factors cuts across the boundaries between many traditional railway industry disciplines and yet adequate management of human factors is often overlooked. Human factors are not a series of independent issues to be conveniently addressed in isolation, or on a piece-meal basis. Nor can human factors be effectively incorporated just before the end of a project or design process. Instead, human factors considerations should be integrated

> throughout the lifecycle of systems development, functions of the owner organisation and the different roles of individuals in project teams. (p.1)

The ORR paper also identifies three key indicators of successful HSI policies (pp. 2-3):

1. Resources and commitment to HSI processes
2. A design process that includes user involvement
3. Assurance and testing

Finally, the ORR paper describes the benefits of successful HSI (pp. 3-4):

- Improved system performance
- Reduction in system whole lifecycle costs
- Reductions in procurement cost and risk
- Improved recruitment and retention
- Removal of health hazards and consequent reduction in liabilities
- Reduced likelihood and severity of accidents

B.4 How Does HSI Work?

HSI is multifaceted. No one approach works best. In general, organizations that acquire or modernize large technological systems may formalize their HSI approach through the following types of activities:

- Obtain a clear commitment from the organization's topmost levels on the importance of HSI in acquiring and modernizing technologies and systems along with adequate resources to implement an HSI process.
- Assign ownership of HSI activities to a human factors professional or other individual (1) within the acquiring organization and (2) within the organization developing the new or modernized systems. Ownership responsibilities include development of the HSI process within his/her organization, development of HSI-related design specifications, and the ability to sign off on HSI-related design specifications.
- Develop design specifications that address HSI domain issues for the technology or system to be procured.
- Develop requirements for user involvement in design and/or testing.
- Use formal human factors techniques (e.g., task analysis) to provide baseline and quantitative (i.e., measurable) data and information to support new designs.
- Require contractors to employ or use formal human factors staff to oversee technology development HSI activities.

B.5 What Are Some HSI Opportunities in the U.S. Railroad Industry?

The U.S. railroad industry continuously seeks to improve the safety and efficiency of its operations through the use of advanced technologies. This has been evident, for example, since railroads transitioned from manual to automatic coupler systems and from manual tie-down to automatic train air brake systems (and most recently, to electronically controlled brakes). Most recently, several significant technologies exist that the industry has begun to study (PTC) or has begun to deploy (RCL operations). Furthermore, railroads are continually upgrading or modernizing existing technological systems, such as computer-aided dispatching (CAD) systems. Lastly, the possibility of new train crew configurations under optimally manned train operations brings with it the expected need for technological (as well as procedural) changes to support these new operations. This section discusses how HSI might play a role in the acquisition or modernization of each of the four major technological systems in the U.S. railroad industry.

B.5.1 PTC Systems

Each of the major U.S. Class I railroads has been exploring the use of PTC systems over the last 20 yr. In January 2007, in fact, FRA approved the first PTC system developed under new 2005 PTC regulations for operation on BNSF Railway. PTC systems may be deployed across the U.S. Class I railroad network if the systems can prove to be cost effective and reliable while increasing safety. It is advantageous to utilize a process of technology acquisition and implementation that includes consideration of PTC users and their anticipated role in operating, maintaining, or otherwise using PTC systems. Without this user-centered approach, a potential mismatch may occur between the PTC users and system operation because human limitations and requirements may be overlooked or otherwise not identified and addressed in the system's design. The result is an increased risk of future operational errors or system failure. For example, when designing the user interface, it is paramount to ensure that appropriate system information feedback is provided to the user to support decisionmaking and maintenance of SA without overwhelming him/her. HSI can also assist system designers in ensuring successful PTC interoperability, a significant goal and necessity for PTC to succeed across the industry.

Anticipated PTC users include train crews, railroad dispatchers, train crew supervisors (i.e., road foremen, trainmasters), communication and signal personnel, information technology (e.g., computer support) personnel, and system maintainers. Consistent with an HSI approach to technology acquisition, the developers should include the job functions of each of these users in specifying and designing PTC systems, including overall function allocation, task requirements, operator interface design, and identification of training requirements on the new systems. All of these factors will influence the design engineering of the PTC system, including the user interface, system functions and operation, and training.

B.5.2 RCL Systems

U.S. Class I railroads began to deploy RCL systems in early 2002. By the beginning of 2006, they had converted a significant percentage of yard assignments to RCL. An opportunity now exists to systematically evaluate RCL effectiveness to identify opportunities to enhance future RCL systems. Such future RCL systems may include new features like switch control and digital video cameras. Some FRA-sponsored research on RCL operations has been conducted that can support HSI evaluation. Furthermore, given that RCL operations have been around for more than 4 yr, railroads can draw on the experiences of RCOs to further understand and identify human factors, system safety, and training issues that may need to be addressed as future iterations of RCL technology are developed and fielded.

B.5.3 CAD Systems

U.S. railroads are experiencing record traffic volumes and seek to continue this growth. One of the ways in which the railroad industry can accommodate increased demand for rail service is through the effective use of technology. PTC systems and RCL operations are two examples. A third example is CAD systems. U.S. railroads, especially the large Class I railroads, are continually improving their CAD systems to enhance the efficiency of their operations. CAD systems, with their route planning and optimization tools, have the potential to help dispatchers and others increase network velocity and boost capacity, thereby improving service and asset utilization.

Various forms of CAD systems have been in place for many years at most of the large railroads and many of the smaller railroads. Consequently, CAD system changes are an example of a system modernization program. That is, each railroad has currently implemented some form of the CAD system. Enhancements or upgrades to a CAD system are designed to improve operational performance while, at the same time, these enhancements must work with some legacy components. Application of HSI principles can help modernize the system by providing a formal means of ensuring that the dispatcher, his/her tasks, and, more generally, dispatcher performance are considered foremost in any changes or updates to the CAD system.

B.5.4 Optimally Manned Train Operations

As railroads continue to seek to make their operations more efficient, an area that will attract more and more attention over the next few years is the possible change in train crew size, makeup, and skill. In order to safely implement any such staffing changes, it is critical to account for all tasks and procedures now carried out by train crewmembers and determine how technology may assist in those tasks and procedures. Application of HSI principles can ensure that all train crew tasks are adequately addressed in the design of advanced technological systems to support optimally manned train operations.

B.6 What Are the Advantages of HSI?

Very briefly, HSI has the potential to:

- Increase U.S. railroad safety by minimizing the potential for system failures through careful consideration of the user as part of overall system reliability and operation.
- Improve operator performance and operational efficiency by specifying and designing the system to accommodate user capabilities and limitations.
- Increase user acceptance through active involvement of users in testing and evaluation, resulting in a human-centered design.
- Reduce training time and costs through design of a human-centered system that requires less specialized training to operate and maintain the technology or system.
- Reduce the likelihood of, and costs associated with, system upgrades and midcourse design changes by carefully considering the user at the start of the design cycle, thereby avoiding human-centered design shortcomings that may otherwise result if the user is not considered early in the design stage. Costs associated with implementing an HSI process

during system acquisition will be less than costs associated with midcourse design changes or post-deployment upgrades.

- Reduce system lifecycle costs by holistically viewing a technological system to include the operators, maintainers, and trainers. Such a holistic view that considers and evaluates the system design, staffing requirements, training requirements, personnel requirements, and system safety will optimize overall system performance, which, in turn, will control or minimize lifecycle costs.

B.7 What Can the U.S. Railroad Industry Do to Implement HSI?

So far, this appendix has introduced the concept of HSI, provided examples of HSI processes and techniques, discussed several technologies where HSI could be introduced, and identified advantages to HSI in the U.S. railroad industry. The U.S. railroad industry has, over time, implemented different aspects of an HSI approach to various technology and modernization programs (for example, use of human factors professionals and human performance data collection methods to design in-cab displays). This section identifies a few specific areas where U.S. railroad management, labor, and suppliers can begin to implement HSI processes and/or techniques. This list is not meant to be exhaustive; rather, it is meant to serve as a starting point and reference. It is understood that some railroads already carry out one or more of the following suggestions.

B.7.1 What Can Railroad Management, Labor, and Trade Associations Do to Implement HSI?

A number of HSI processes and techniques exist that the railroad industry—railroad management, labor unions, and trade associations, such as AAR and American Short Line and Regional Railroad Association—can adopt and implement. Some, of course, have already been adopted. The following short list includes a host of possible HSI processes and techniques. Not all need to be followed in any one program. In general, the more that are followed, the more robust will be the HSI.

- Allocate sufficient monetary and staff resources to develop an HSI program to support system acquisitions and modernizations.
- Develop an overarching HSI policy and process that governs how HSI will be applied to new system or technology acquisitions and modernization programs. While railroads would be responsible for developing their own HSI policies, a trade organization could support this process by developing a guidance document on how railroads can establish an HSI process. AAR, for instance, already produces a variety of guidance documents (e.g., Locomotive System Integration Operating Display Standard S591; AAR, 2006) to support railroad technology development and use in the U.S. railroad industry.
- Develop an HSIP for each new or modernization program. Among other purposes, the HSIP should indicate how human factors requirements will be addressed during the program, convey the scope of human factors work to be performed, identify critical human factors milestones and constraints, assign roles and responsibilities, and provide a means of recording and resolving problems and trade offs.

- Appoint a human factors champion to each program to ensure that human factors are considered and included in the design and development stages.
- Incorporate human factors engineering data collection and analysis techniques to understand users, the tasks, and the operational environment. These techniques are best utilized proactively to ensure that users and their tasks and interactions with equipment, people, and procedures will be optimized. An example is conducting risk assessment methods, such as a failure modes, effects, and criticality analysis, to identify and prioritize potentially hazardous scenarios and conditions associated with a new system.
- Use quantifiable and documented human factors engineering data to guide and support HSI design specifications and requirements.
- Use HSI design specifications and requirements to support the statement of work and the specific tasks that a technology or system supplier must complete when developing the technology or system to be acquired.

B.7.2 What Can Railroad Suppliers Do to Implement HSI?

A number of HSI processes and techniques also exist that railroad suppliers can adopt and follow to support the railroads in their efforts to acquire new technologies and processes and modernize operations. Undoubtedly, different suppliers have already incorporated some of these approaches. The following list is meant to serve as a starting point and reference. A few HSI approaches include the following:

- Employ and use human factors professionals on railroad programs to ensure that user capabilities, limitations, and requirements are considered and included in system designs.
- Involve human factors specialists at the earliest stages of, and throughout, system design and development.
- Use human factors data collection and analysis techniques to collect quantitative and qualitative user performance, preference, and acceptance data when developing new or modernized systems. Start with fundamental baseline data, such as results from task and job analyses.
- Ensure design decisions for new and modernized systems, including human factors and human performance data, to the extent possible. Sources of data may be internal usability tests or published information, such as anthropometric data. One approach to ensuring the use of human factors and human performance data is for suppliers to develop an internal quality standard that requires the use of these data as part of their design and development process.
- Ensure that designers have a mastery of the subject domain for which the new technology or system will be used. This might involve utilizing in-house SMEs, hiring an SME consultant, or including railroad SMEs as part of a design advisory group.
- Ensure that the system being developed satisfies all of the contracting railroad's human-centered design requirements and specifications.

B.8 References

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Abbreviations and Acronyms

AAR	Association of American Railroads
ANSI	American National Standards Institute
CAD	Computer Aided Design
CFR	Code of Federal Regulations
DoD	Department of Defense
DOE	Department of Energy
FAA	Federal Aviation Administration
FRA	Federal Railroad Administration
GE	General Electric
HCTOOL	Human-Centered Technologies Tool
HFE	human factors engineering
HFI	human factors integration
HSI	human systems integration
HSIP	human systems integration plan
ISO	International Organization for Standardization
KSAOs	knowledge, skills, abilities, and other characteristics
MANPRINT	Manpower and Personnel Integration
MOD	Ministry of Defense
NTSB	National Transportation Safety Board
OCC	onboard control computer
OCU	operator control unit
ORR	Office of Rail Regulation
PTC	positive train control
RCL	remote control locomotive
RCO	remote control operator
RCZ	remote control zone
SA	situation awareness
SME	subject matter expert
TSB Canada	Transportation Safety Board of Canada
yr	year(s)