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An Acquisition Approach to Adopting Human Systems Integration in the Railroad Industry

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13. ABSTRACT (Maximum 200 words)

This report provides guidance on how the railroad industry can develop safer systems by acquiring new equipment based on human-centered design practices, or Human Systems Integration (HSI). If a railroad's system design approach is focused on properly integrating people with technology, it can greatly enhance safety and system efficiency by reducing the risk of human error and improving overall system performance. The report explains how to transform general HSI guidance into specific requirements statements in contract format; these requirements can be included in requests for proposals issued by railroads for new equipment. The system and human performance requirements guidance focus on (a) Program Management and Control, (b) Analysis, (c) Design, and (d) Test and Evaluation (T&E).

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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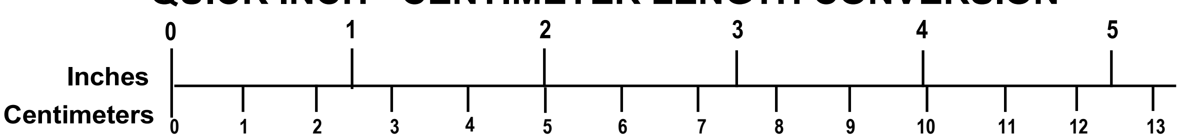
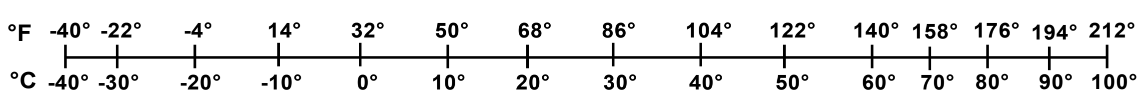
QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

This report describes how the railroad industry can incorporate a human-centered design approach into their procurement process for new railroad systems. Related advice is also provided to railroad equipment vendors.

Human Systems Integration (HSI) is a systematic process that integrates human performance considerations into the design and acquisition of complex systems (Malone et al., 2007; Reinach and Jones, 2007). It uses systems engineering (SE) processes "[to ensure that] all human-related technical issues are properly identified and addressed during […] planning, design, development, and evaluation" of technical systems (Folds, 2015). Implementing HSI can reduce system safety risks and performance risks, and it can also minimize the frequency of redesigns caused by human factors issues that would otherwise have been found later in the system development process. This could yield considerable cost savings to railroads over time.

This document provides two forms of acquisition guidance that engage with HSI:

- *Contractor Proposal Requirements:* Specific items that a railroad can require their vendors to fulfill. These suggested requirements are in the form of "shall" statements that can be directly inserted into procurement documents. These requirements fall into four categories: (a) Program Management and Control, (b) Analysis, (c) Design, and (d) Test and Evaluation (T&E). This report describes the reasoning behind each requirement and summarizes all recommended requirements in Appendix A.
- *General Guidance:* The report provides additional discussion about acquisition guidance and HSI. Examples include weighing qualifications of vendors' HSI practitioners and using multidisciplinary teams to provide advice on human performance issues. The authors also strongly advise procuring railroads to acquire in-house or contract HSI expertise of their own.

The report also recommends during the contract proposal preparation, that vendors submit an HSI Program Plan (HSIPP) – a document detailing the vendor's HSI-related qualifications, organizational structure, and human engineering activity planning. Appendix E contains a recommended template for vendors.

1. Introduction

1.1 Overview

This work describes how to incorporate the Human Systems Integration (HSI) methodology into acquisition processes for complex railroad technologies. It also provides guidance for the railroad industry on creating HSI-related acquisition requirements.

HSI[1] is a system that integrates human performance considerations into the design and acquisition of complex systems (Malone, Savage-Knepshield, & Avery, 2007; Reinach & Jones, 2007). It adds a set of analysis, design, and evaluation methods into the systems engineering (SE) process to ensure that all human-related technical issues are appropriately identified and addressed during the planning, design, development and evaluation of technical systems (Folds, 2015).

In the railroad industry, the vendor[2] is usually responsible for designing and implementing new systems. As a result, railroads use the acquisition process to influence how systems are developed and implemented. This report explains how railroads can bring HSI into the railroad SE process[3] by creating requirements that their vendors must follow during system development. This approach still allows for significant flexibility when producing specific system requirements.

For freight and passenger railroads, the HSI process applies across a wide range of new technologies and can be involved in the modernization of existing systems. This report addresses the challenges the rail industry currently faces with designing and implementing cab displays and controls. The report begins with a discussion of cab display issues, and then segues into the growing use of HSI, what HSI encompasses, what it can help to address, the return on investment for HSI, and a high-level overview of how it ties into SE.

Section 2 of the report provides HSI acquisition guidance including specific HSI-related requirements in the form of 'shall' statements, which can be directly inserted into procurement documents for vendors to follow (also listed in Appendix A).

1.2 Background

The demand to improve productivity and safety has increased the emphasis (or focus) on technological development in both freight and passenger rail operations. The following are the two most common automation-related technologies:

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[1] In systems engineering, human factors engineering is commonly used instead of HSI, treating the two terms synonymously. However, HSI is a broader subject that encompasses human-centered issues that extend beyond human factors engineering (e.g., identifying staffing and training requirements). Given the distinction between the terms, this report uses HSI unless specifically referring to the human factors engineering subdomain of HSI.

[2] The term "vendor" refers to the organization hired to engineer and build equipment, systems, or facilities for the procuring organization (typically a railroad) under the terms specified in a contract.

[3] The report does not discuss in detail the systems engineering process since other sources are available as reference (e.g., Blanchard & Fabrycky, 2011; INCOSE, 2015).

(1) *Energy Management* (EM) systems, which serve as decision aids for operating trains with improved energy efficiency, or they can control trains with the locomotive engineer supervising the automation.

(2) *Positive Train Control* (PTC), which can prevent several classes of accidents involving train separation by enforcing speed limits and protecting employees who are working on rights-of-way.[4]

Because these technologies are not integrated into one operating system, problems such as possible conflicting system interactions, inconsistent or incompatible controls and displays, and lengthy training for every system may lead to operational risks for the operators or train crew. Each of these technologies interact with train controls and therefore affect how the locomotive engineer manages the train. Furthermore, even though they were built independently, the technologies should be integrated for ease of understanding and operation by locomotive crew.

Railroads need to implement these technologies in a way that allows the engineer to understand and interact with the train under a new control paradigm. Prior to implementation, the railroad industry needs to address the following questions that arise:

- Given the limited space for new controls and displays, how should designers present the information needed to interact with these systems?
- How will the roles of the locomotive engineer and conductor change as railroads introduce these and other new technologies into the cab?
- What kinds of controls will designers provide for managing these technologies?
- Because these technologies change how trains are operated, will these separate system functions be integrated into the train control system? I.e., will the separate components be designed to cooperate with each other? If so, will the integrated systems help the locomotive engineer understand how the technologies affect the operation of the train?
- How will the new technologies impact teamwork within the cab and communication, and coordination with other railroad workers (e.g., dispatchers, roadway workers)?
- How will staffing and training be affected?

HSI provides tools for analysis, design, and T&E that can help to answer these types of questions.

The issue of interoperability across multiple railroads must also be addressed. As each railroad creates a signaling and operational system that meets its own needs and specifications, trains that cross different railroad areas must have interoperable systems. Interoperability may require a common human-machine system interface that alerts the train crew to changes in territorial operations or rules, and helps them to conduct safe operations. HSI does not take a prescriptive approach to designing this interface, but the methodology works to improve crew situation awareness and reduce the risk of human error by requiring design processes that specifically

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[4] In 2008, Congress required Class 1 freight railroads to implement PTC and have these systems operational by the end of 2015. However since then, Congress passed a three-year extension for the installation of PTC, giving the railroads until the end of 2018.

address crew needs for decision-making and safe operation. In this way, crew requirements augment the electronic requirements of the system.

1.3 Approach

The authors recommend that the railroad industry adopt HSI, an approach that integrates human performance considerations into the design and acquisition of complex systems, rather than exclusively relying on prescriptive standards for locomotive cab displays and controls.

Since display and control standards impose specific requirements on the design product (e.g., the exact look and feel of cab controls and displays), they:

- Can be too vague (in an attempt to be broadly applicable) or too rigid (in an attempt to impose consistency);
- Do not provide guidance on how to proceed when different standards give conflicting advice;
- Can only address existing technology and knowledge; and
- Need to be periodically updated to maintain relevance, which is a difficult task (especially as stakeholder interests diverge).

In contrast, HSI imposes requirements on the design process to identify and address human performance issues as part of the overall system design. In doing this, the methodology:

- Enables display and control standards to be flexibly applied;
- Provides the ability to balance competing requirements;
- Applies to both current and future technologies; and
- Does not require frequent updating.

Perhaps most importantly, implementing HSI can provide considerable return on investment. It can minimize the frequency of redesign by resolving human factors issues that otherwise would have been found late in the SE process.

This section explains the above concepts in greater detail, and shows how the inclusion of HSI practices and acquisition requirements outlined in this report can result in better outcomes for railroad systems.

1.3.1 Use and Limitations of Prescriptive Standards

Prescriptive standards can contribute to uniform designs that promote the interoperability of components across multiple railroads and make it easier and safer to learn and operate new technologies. They are particularly important for ensuring good display design, effective use of auditory warnings, and other important elements in human factors engineering. For example, the cab design discussion from Section 1.2 involves several railroad industry guidelines that can be utilized in the cab design process, including the AAR's S-591 Locomotive Standard for Locomotive Cab Displays (Association of American Railroads, 2008), European Train Control System Driver Machine Interface specifications (2012), US Human Factors Guidelines for Locomotive Cabs (Multer et al., 1998), and Appendix E of 49 CFR Part 236 which details the

Federal Railroad Administration's (FRA) human-machine interface[5] design criteria for PTC systems. There are also general design guidelines and standards developed by other industry and government organizations that may be relevant to railroads, such as the widely used MIL-STD-1472 or ISO 9241.

While prescriptive human factors engineering standards are important, they do not *by themselves* ensure a safe system that meets transportation requirements. Reasons for this include the following:

- **Human Factors Engineering (HFE) standards can sometimes be too vague or too rigid**. A common problem with human factors standards and guidelines is that they may sometimes be too vague, in an attempt to apply across a variety of situations, or too specific, in an attempt to enforce consistency (Baber, 2015). A process-oriented HSI approach allows for more flexible application of prescriptive standards. HSI methods can be used to provide objective and measurable criteria for standards that might otherwise be considered vague. For example, HSI includes analyses (e.g., cognitive task analyses) that can be used to define the precise information requirements that will support locomotive engineer situation awareness of events and changes both inside and outside the cab.

  HSI can also provide objective data that justify exemptions from some standards. For example, a human-in-the-loop evaluation, which is a key element of HSI, can establish whether using more than seven colors over a group of displays detracts from or enhances performance in the case of a particular railroad application (e.g., a suite of displays for a railroad dispatch center). The test results can be used to justify an exemption from a requirement that has an upper limit of seven colors across displays.

- **HFE standards do not address tradeoffs.** The use of human performance standards does not prevent the need for design tradeoffs to accommodate conflicting design goals and constraints. When faced with design constraints or conflicts, the designer or system engineer may have to adapt the design in a way that meets some elements of the standard while diverging from other elements. For example, a typical design requirement might state the need to "*Adopt a consistent format for all display screens by placing each design element in a consistent and specified location*." In some circumstances, this design requirement may conflict with another typical human factors design requirement that states the need to "*Display critical information in the center of the operator's field of view by placing items that need to be found quickly in the upper left hand corner and items which are not time-critical in the lower right hand corner of the field of view*."

  Conflict between design requirements may arise when a given piece of information appears on multiple displays, but is more critical to task performance in some displays than in others. For example, fuel usage may be useful in the main display used by locomotive engineers during normal train operation, but that indicator may not be critical as safety sensitive information like train speed, signal status and other safety sensitive information. Therefore, the fuel usage indicator can be placed in a less prominent location. In contrast, a secondary display focused on fuel usage may place the fuel usage indicator in a more prominent location. Such a secondary display may be used to train locomotive engineers in strategies for optimizing fuel usage. Display designers need to

[5] This report uses the term human-system interface rather than human-machine interface.

consider the rationale and relative importance of conflicting requirements when they decide where and how to present fuel usage in the two displays that have very different purposes. A process-oriented HSI approach explicitly recognizes the need to balance requirements and make tradeoffs.

- **HFE standards reflect the limits of existing technology and knowledge.** Any standard developed today may not be applicable to future locomotives. Existing human factors guidelines reflect the limits of the existing technology (e.g., display resolution) and the current understanding of the how human performance interacts with technology. As existing technology improves and new research extends our understanding of how human performance and technology interact, human factors guidance must reflect these changes. This means that standards may need to be updated to maintain relevance and utility. An HSI design approach is applicable to a wide variety of technologies – including those that have not been envisioned yet.
- **HFE standards may take a long time to develop when the process for creating standards call for agreement across different stakeholder groups.** Updating them with a consensus based process may be challenging in the railroad environment, where stakeholders interests may diverge. Because a long-lead time is necessary to obtain agreement from all parties, changing the standards can also be a long and slow process that happens infrequently. By contrast, technology changes rapidly as companies innovate to accomplish the same task (e.g., display information). As a result, the railroad standards may lag behind the rapid pace at which technology changes. A process-oriented HSI approach does not require frequent updates because process requirements can remain largely unchanged over time.

Because of the limitations mentioned above, human factors engineering standards and guidelines should not be the sole means for ensuring good human factors design. Instead, the authors recommend complementing HFE standards with HSI requirements that apply to the design and development process, such as requiring regular feedback from representative users during the design process, and requiring formal performance-based user evaluations as part of the system T&E program (Baber, 2015; Gray & Stewart, 2015).

1.3.2 Human Systems Integration (HSI)

This section provides more background about HSI:

- The origin of HSI and how it relates to rail safety and performance
- The scope of HSI and what issues it addresses
- How HSI fits into SE
- The return on investment (ROI) generated by HSI

1.3.2.1 The Growth of HSI

In the early 1980's, HSI was created to reduce human performance related accidents; decrease manpower, personnel and training costs; and reduce total life cycle systems costs. The U.S. Army was the first major organization to implement HSI concepts when it created the Manpower and Personnel Integration (MANPRINT) management and technical program in 1986 (Booher, 2003). As General Max Thurman of the U.S. Army asserted, *"We must quit manning the equipment and start equipping the man."* (Air Force, 2009).

Since the Army first implemented MANPRINT, HSI has become more widely accepted and it has been adopted by multiple branches of the military, NASA, and the FAA as well as various industries (Booher, 2003; Pew and Mavor, 2007; Boehm-Davis, Durso and Lee, 2015; US Air Force, 2009). The International Council on Systems Engineering (INCOSE) explicitly includes HSI as one of the specialty engineering activities in its most recent systems engineering handbook (INCOSE, 2015).

The railroad industry has increasingly recognized the need for HSI, as software intensive railroad systems become more complex and impose greater cognitive demands on railroad workers. The prime example, as discussed above, is the need to integrate multiple new technologies into the locomotive cab. FRA has been leading the effort to introduce HSI concepts to the railroad industry via white papers (Reinach & Jones, 2007), research reports, and playing a role in an industry Technology Advisory Group in the past several years. Commercial rail transit vendors have also made nascent efforts at incorporating HSI methods. For example, New York City Transit's Integrated Service Information and Management system development project recently adopted a system engineering process that incorporates HSI methods (Colacioppo, 2015). However, much remains to be done. In 2016, the railroad industry does not have an HSI framework in place for system design and technology acquisition and implementation. This document fills that gap by providing a rationale for introducing HSI to the railroad industry and a roadmap for how to do it. The objective is to provide railroads the tools they need to ensure that human performance considerations are more fully integrated into the design and acquisition of complex systems so that safety, performance, and cost risks are reduced.

1.3.2.2 Scope of HSI

HSI begins during initial capability definition and requirements gathering, continues through design and construction phases, and moves on through deployment and operational feedback. HSI emphasizes systems integration to ensure that the individual elements of the system are analyzed and designed as an integrated whole. For example, when physical equipment is designed, the pieces that will be installed in a locomotive cab need to be considered in unison to avoid unintended negative interactions. For example, where independently developed technologies are paired together, different displays may provide contradictory or conflicting information or guidance. Further, HSI's scope encompasses the range of personnel that will interact with the technology and their needs, including operations, maintenance and support. The end goal of HSI is to optimize performance, reduce the potential for human error and minimize total life cycle ownership cost by enhancing whole system safety and efficiency (Reinach & Jones, 2007). (See further discussion regarding return on investment for HSI in Section 1.3.2.4.)

HSI goes beyond the design of specific hardware and software and considers the implications for staffing and training of personnel as well as the considerations needed for safety and occupational health. The US Army's MANPRINT program identified seven HSI domains: manpower, personnel, training, human factors engineering, safety, occupational health, and survivability. More recently, some organizations expanded the scope of HSI to include two additional domains: environment and habitability (Durso, Boehm-Davis & Lee, 2015). While the domains that are included by different organizations vary, depending on their scope of concern, there is general agreement on the importance of including six core HSI domains: manpower, personnel, training, human factors engineering, safety, and occupational health (Durso, et al., 2015). Table 1 lists and defines all nine HSI domains.

Table 1. Human Systems Integration Domains

HSI Domains	Description
Manpower	Number and mix of personnel required and available to operate, maintain and support the system.
Personnel	Human knowledge, skills, abilities, and experience levels required to operate, maintain, and support the system at the time it is fielded and throughout its life cycle.
Training	Instruction and resources required to achieve the knowledge, skills, and abilities needed by the personnel to properly operate, maintain and support the systems.
Human Factors Engineering	Comprehensive integration of human capabilities and limitations (cognitive, physical, sensory and team dynamics) into system design, development and evaluation to optimize joint human-system performance.
Safety	Design and operational characteristics that minimize the possibilities for accidents or mishaps that can cause death or injury to people and/or damage to property or the environment.
Occupational Health	Design features and intrinsic conditions in the operation or use of a system that minimize risk of injury, acute or chronic illness or disability and reduced job performance of personnel who operate, maintain, or support the system.
Environment	Environmental considerations that can affect operations and requirements, particularly human performance.
Habitability	Characteristics of the system living and working conditions that are necessary to sustain morale, safety, health and comfort of the user population.
Survivability	Human-related characteristics of a system (e.g., helmets, seat belts, egress/ejection equipment) that reduce susceptibility to acute or chronic illness, injury, disability or death.

HSI emphasizes the importance of considering the interactions and tradeoffs across the HSI domains during the requirements identification and technology development process. For example, manpower and personnel decisions (e.g., a desire to reduce the number of personnel required to operate or maintain a train, ship or aircraft) can have strong implications for automation requirements as well as the designs of displays and physical layouts. Similarly, automation level and technology complexity may impose additional requirements on personnel selection (e.g., level of education required) and training needs for operating, maintaining, and/or supporting systems. These tradeoffs need to be explicitly considered early in the technology procurement and development process to ensure effective performance and minimize total system lifecycle cost.

1.3.2.3 Integrating HSI into the Systems Engineering Process

At the highest level, the SE process involves analysis activities, design and development activities, and Testing and Evaluation (T&E) activities. HSI incorporates *user-centered* analysis, design and development, and T&E activities into SE (Pew & Mavor, 2007):

- *Analysis Activities* develop and refine system requirements (many of which are captured in the conceptual design stage of SE)
- *Design and Development Activities* develop a system design that meets system goals and requirements (corresponding to preliminary design and detail design SE stages)
- *T&E Activities* establish that the system requirements as specified have been met (referred to as verification activities) and that the final designed system meets high-level system goals such operating safely, efficiently, and effectively (referred to as *final system validation* in this report).

Figure 1 provides a high-level overview of the major HSI analysis, design and development, and T&E activities (adapted from NASA/TP-2014-218556, 2014). While the major activities in this figure are listed sequentially, the arrows shown on the left are intended to serve as a reminder that the process is in fact iterative with results from later activities feeding back and resulting in revisions to findings from earlier activities. This general process may need to be tailored to the of the acquisitioning railroad's specific goals and constraints.

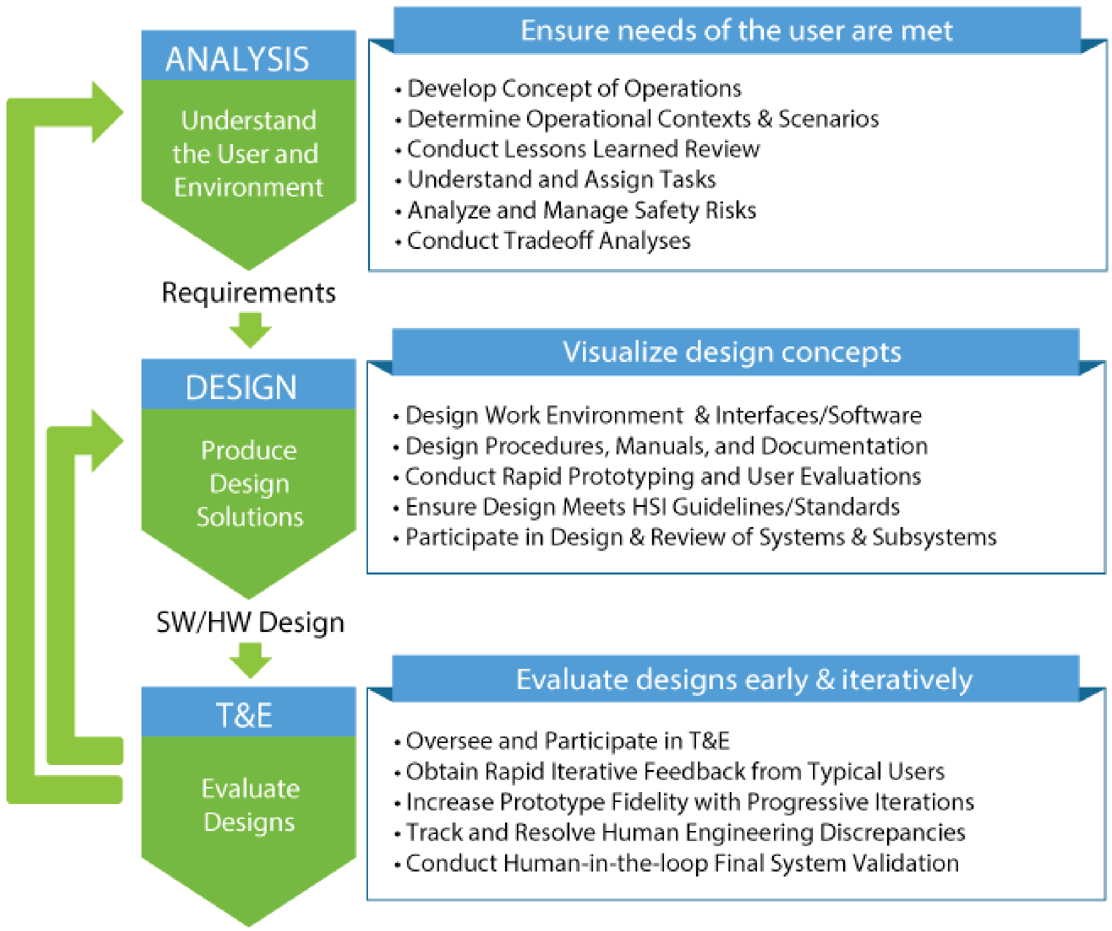

Figure 1. An overview of major HSI activities (adapted from Figure 3.2.3-1 in NASA/TP-2014- 218556).

The HSI process starts during the SE phase *Analysis Activities*. It focuses on understanding the users of the technology, the cognitive and physical tasks they will need to perform, and the broader contextual environment within which the work will be performed so as to ensure that the needs of the user and the overall system performance objectives are met. In this phase, the following information is developed:

- A concept of operation, which describes the anticipated users' role in the new or redesigned system
- The objectives of the new or redesigned system in terms of user performance (i.e.., a reduction in staffing; an improvement in safety; an improvement in train handling or fuel usage efficiency)
- The operational situations and complexities that need to be accommodated
- The user functions and tasks
- The human performance issues and design challenges to be addressed
- The impact of human performance on risk and safety

- What can be done to reduce errors
- How the system can enhance the ability of people to recognize and mitigate safety critical situations.

HSI identifies user needs and performance challenges to minimize program risk (in terms of schedule and cost) and optimize system safety (reduce the potential for human error and accidents).

The success of the analysis phase, as well as the related design and evaluation phases, depends upon the active involvement of users and a clear understanding of user and task requirements and performance challenges. Users provide valuable knowledge about the context of use, the tasks, and how users are likely to work with the system. The analysts can solicit information from system users through interviews, focus groups and observations of their tasks and challenges in their current work environment.

The analyses contribute to the HSI requirements that inform design and development. These requirements need to be coordinated with other system requirements and integrated into the system requirements development process. The HSI requirements will be refined and revised throughout the design and development process as new user needs are uncovered and system requirements are updated.

In *HSI Design and Development Activities*, alternative ways (combinations of hardware, software and people) to create the desired system functionality are identified and evaluated. A key to effective design is to provide ways for stakeholders, including the target users of the system, to visualize the design concept and propel design improvement with informed feedback. Design concepts can take many forms ranging from paper and pencil sketches, to interactive software prototypes to high-fidelity mockups and simulations, depending on the level of maturity of the design.

Due to the increasing complexity of railroad systems, successful design involves an iterative design and test process, where designs are refined based on user feedback until an acceptable solution is achieved. In early iterations, designers may present concepts and solicit input on potential areas of concern and opportunities for improvement. In later iterations, users may be given hands-on experience with a prototype, which allows the designers to collect objective performance data and identify sources of confusion and error-inducing situations. This iterative process provides a mechanism to make tradeoffs as well as balance competing needs and constraints related to human performance, technology, cost, environment considerations, etc.

HSI T&E Activities are conducted throughout the SE process to ensure that the designed system meets HSI requirements (verification activities) and that it effectively enables users to operate safely, efficiently, and effectively (validation activities). HSI T&E activities begin early and continue throughout the design and development process, culminating in a more formal integrated validation (referred to as final system validation in this report), which involves a human-in-the-loop operational test. Initial T&Es occur as part of the iterative design process. The objective is to identify risks and issues early in the design cycle when they are relatively inexpensive to fix. Initial evaluations may take the form of informal reviews with users and stakeholders.

As the design matures and rapid computer-based prototypes become available, HSI practitioners can conduct formal usability tests where qualitative observations, quantitative performance data, and user feedback can identify design deficiencies that need to be addressed in later design cycles. Once the design is completed and ready for acceptance testing, HSI practitioners should conduct a more formal and comprehensive final system validation, including human-in-the-loop testing, using a range of realistically challenging operational scenarios. This can occur in the actual operational context (with appropriate safety protocols) or in a high fidelity simulator. The final system validation determines whether the system functions safely and effectively under a range of challenging operational situations. The HSI practitioner should document any deficiencies and include a detailed description of the deficiencies, any operational impacts, and recommended corrective actions.

It should be stressed that these three types of activities are not linear. While the SE process is often described as a linear progression (moving from well-defined requirements to system designs and then evaluation), it is widely recognized to be iterative (Blanchard & Fabrycky, 2011; Boehm-Davis, Durso, & Lee, 2015; FAA, 2009; NASA 2014, NUREG-0711, 2012). It converges toward a solution but the process requires that prior system elements and decisions be revisited as the understanding of stakeholder objectives, user needs, and the implications of stated requirements or proposed designs become clearer (Pew & Mavor, 2007). HSI processes are similarly iterative. HSI is guided by feedback loops, involving close interaction with stakeholders, other system engineers and the target users of the system.

In practice, analysis, design and development, and T&E activities often go on concurrently (Pew and Mavor, 2007) with changes in level of intensity of each of the three types of activities across the system development process. Figure 2 provides a stylized schematic intended to highlight this point.

Analysis activities are more frequent in the early stages of system development process when initial concepts are being explored and requirements are being formulated, but continue throughout the design and development process. Design and development activities start in parallel, beginning with initial concept designs, increase in intensity during the middle design phases when preliminary designs are generated and then refined as part of detailed design. T&E activities go on throughout the design and development process, providing periodic heading checks that culminate in a final system validation (including human-in-the-loop testing) that the final design meets user needs and stakeholder objectives.

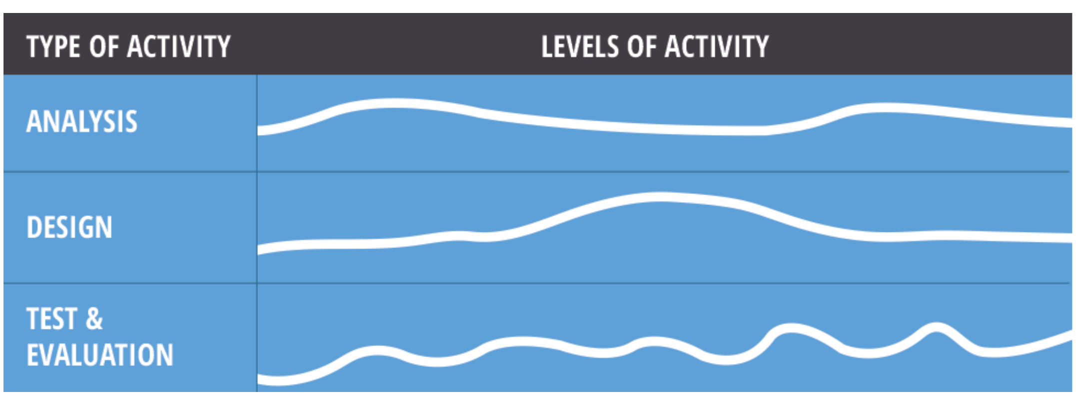

Figure 2. Levels of activity of analysis, design and test & evaluation across the system development process (adapted from Pew and Mavor, 2007).

1.3.2.4 The Case for HSI

By requiring vendors to utilize an HSI approach that considers the strengths and weaknesses of the humans in the system, railroads can design, develop, operate and maintain a system that better meets their needs at lower cost. The increasing pace of technology development and the demand for changes to the design and operation of existing railroad systems calls for a process that can keep pace with these changes. An HSI approach to railroad system design, and locomotive design in particular, provides a process that allows the industry to better meet their business requirements and satisfy the ever increasing demands for safer systems by the public, the Congress and regulators. This section makes the case for how HSI can support the railroad industry in acquiring systems that better meet their needs, improve safety, and lower overall cost.

If HSI is involved early in the design process, it can manage risks before system implementation, which can deliver improved benefits in terms of safety, operation and cost management It can also provide an opportunity to represent the users' needs and to take human capabilities and limitations into account at the same time that designers consider technologies for adoption in the system (Grimes et al., 2009). However, if HSI is considered late in the design process, many design decisions have already been made and those decisions constrain the ability of the design team to address human performance considerations.

Figure 3 illustrates how the number of designs that can be considered decreases while progressing through the development cycle while the costs of those design changes increase (Ehrlich and Rohn, 1994). These earlier decisions constrain which solutions can be considered. For example, when a signal system is chosen, that decision affects the wayside infrastructure as well as the display of information in the locomotive and the office environment where the dispatcher works. The high cost of signal systems and the interactions with other parts of the railroad system make it technically challenging and expensive to modify the system after the signal design has been completed.

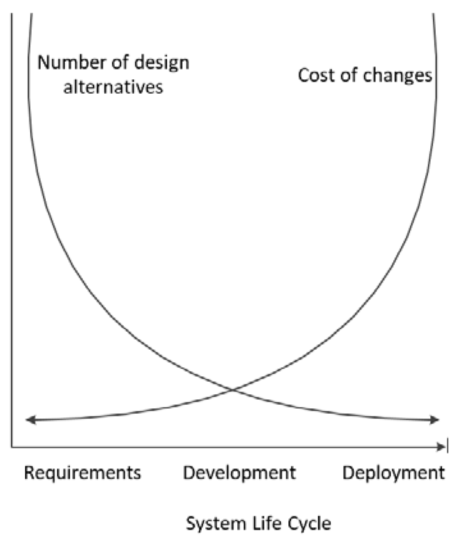

Figure 3. Relationship between design alternatives that can be considered and the cost of changes by the system development lifecycle. Adapted from Erlich and Rohn (1994).

Design modifications tend to increase in cost, since the design becomes fixed as it is implemented. The cost of addressing human performance issues is illustrated in the following formula (see Figure 4) calculating the Return on Investment (ROI) for avoided expenditures (Grimes et al., 2009). In this formula, *Avoided Expenditure* is the cost avoided by doing HSI work early in the project, thus avoiding expensive modifications. This is akin to "gain from investment" in traditional ROI calculations. *Investment cost* is the funding needed to do the HSI work.

$$\text{ROI} = \frac{\textit{Avoided Expenditure - Investment Cost}}{\textit{Investment Cost}}$$

Figure 4. Formula Calculating ROI for Avoided Expenditures

Consider the following fictitious example in which two additional displays were added into the cab—one for an energy management system and one for a positive train control system—in addition to the two displays that exist in the cab. Multiple displays made it difficult for the locomotive engineers to determine where to focus their attention. As a result, they overlooked important speed control information, which resulted in the very warnings to reduce or change speed that the systems were designed to prevent or mitigate. Then additional work was needed, which could have been avoided if HSI was considered early in the process: HSI feedback was generated for the design, the system was redesigned (taking the HSI input into consideration) to accommodate the information from the four cab displays into a single integrated display, and a temporary training workaround was developed to reduce the potential for missing critical information. The sample ROI calculation is shown in Figure 5.

System Redesign Costs (Avoidable Expenditure)		
System redesign	$300,000	**ROI** = ($450K - $100K) ÷ $100K
HSI input on redesign	$100,000	= 3.5 or 350%
Temporary workaround	$50,000	
Total	$450,000	
Investment Costs		
HSI input on initial design	$100,000	

Figure 5. Sample ROI Calculation

The ROI for this example would be 3.5, or 350%. Performing HSI work during the original design process, before the additional two displays were added, would have saved 3.5 times the cost of the original design work.

The HSI process contributes to system safety much like the job safety briefing does. During a job safety briefing, which train crews and maintenance employees perform before beginning a task or when there is a significant change in working conditions, the crew will discuss the work they will perform and identify any safety risks that could occur along with how they will address these risks, should they arise. Like the job safety briefing, the HSI process enables an organization to plan for known and unknown risks that involve human performance and design solutions to prevent or minimize them.

As an additional benefit, the HSI process can also consider the impact of particular designs on employee selection, training, and maintenance, as well as operations. Considering these factors before the design is implemented can reduce the total cost of ownership (TCO). For example, as railroad systems have increased in complexity, the railroads have increased the educational level required for some employees. This reduces the potential pool of employees and contributes to increased labor costs. By thinking about the labor pool available and what skill level you expect from employees before the design is developed, the design team has a chance to adapt the technology to meet those skills and expand the pool of people who can do the work safely. It can also contribute to reduced training costs. To the extent that the designers create a system that matches how people think and act, railroads can reduce the time and costs needed for training. Likewise, by thinking about how to minimize maintenance and designing the maintenance activities and technologies to be compatible with human performance constraints, the railroads can reduce the costs associated with these activities.

2. HSI Process Guidance and Requirements

2.1 Overview

This section provides guidance on how railroads can incorporate HSI into their acquisition process. The current guidance takes two forms: requirements and general guidance/best practices.

- ***Requirements:*** Specific requirements that the vendor must meet are presented in the form of "shall" statements. The procuring organization's acquisition team can incorporate the requirements directly as written into procurement documents (or with modification if railroad HSI practitioners find that changes are needed for a particular procurement). Accompanying text provides rationale for the requirements and more details on how they can be met. The requirements themselves are shown within shaded boxes, such as the one shown below. Requirements fall into one of four categories:

  (a.) Program Management and Control;

  (b.) Analysis;

  (c.) Design and Development; and

  (d.) T&E.

  Within the requirement text boxes, there are some words that are bolded with an underscore between words in the same term. This denotes that the bolded item has an accompanying entry in the requirements glossary (Appendix B).

["shall statement"]

- ***General Guidance and Best Practices:*** There are some topics that the authors did not need to constrain the railroad vendor with a formal requirement, but this report still provides some discussion. These topics have headings and provide general information and suggestions for best practice.

One particular requirement deserves special attention because it is qualitatively different from the others. This is the requirement for vendors to submit an HSI Program Plan (HSIPP) that specifies, among other things, their HSI-related qualifications, organizational structure, and activity planning.

Railroads should require vendors to submit the HSIPP prior to contract award (i.e., as part of their submittal in response to a request for proposal). Requiring vendors to submit an HSIPP as part of their proposal package will (a) aid railroads in judging proposal quality and making an award decision and (b) facilitate the vendor's front-end HSI planning, which is critical to success.

The appendices provide the following assistance to those who are interested in HSI requirements:

- *Appendix A* – Lists all recommended requirements.
- *Appendix B* – Contains a glossary of terms used in those requirements.
- *Appendix C* – Provides verification questions for each requirement that details objective evidence than can be used to establish whether or not that requirement has been met.
- *Appendix D* – Provides a summary listing of HSI-related 'data items' that the authors recommend vendors produce in the course of the system development program.
- *Appendix E* – Provides a HSIPP template and instructions.
- *Appendix F* – Provides a list of resources for HSI training.
- *Appendix G* – Lists further readings that provide more in-depth description of the concepts and methods discussed in this section. These further readings are organized by topic area and cross-reference the section number where the topic is discussed in this report.

The set of requirements listed in Section 2 are closely modeled on, and borrow heavily from, the Federal Aviation Administration (FAA) standard "Requirements for a Human Factors Program" FAA HF-STD-004.[6]

2.2 Program Management and Control

Program management is an important part of any SE project and there are multiple program management considerations that are particularly important from an HSI perspective. The majority of the program management requirements discussed below are directed at vendors. The last subsection, Section 2.2.6, provides program management guidance directed at the railroads themselves.

The following considerations, which are fully described below, are part of program management and control:

- *Human Systems Integration Program Plan (HSIPP)* – What information should be included in an HSIPP and what are the benefits of requiring vendors to submit this document prior to contract award?
- *Integrating HSI Practitioners* – Why is it important to integrate HSI practitioners into SE process and how can this be accomplished?
- *Program Risk Management* – How can program risks related to human performance and HSI issues be identified early and best managed?

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[6] FAA HF-STD-004 is the FAA's standard for acquiring new systems using HSI, and many of their requirements are relevant to railroad HSI. (Please note that FAA uses the term "human factors" instead of "Human Systems Integration.")

- *Traceability* – How can the vendor ensure that the final system still meets the initial HSI requirements identified (such as operational objectives, constraints, and accompanying design implications)?
- *Operational Experts* – What role do operational experts play and what operational experts should participate in this process?
- *Railroad HSI Expertise* – Given that it's the vendors that are designing and building the system, why is it critical that the procuring railroads also have HSI expertise on their end?

2.2.1 Human Systems Integration Program Plan (HSIPP)

It is critical to make sure that vendors have thought through, as early as possible, how they will accomplish the HSI contract requirements for the specific system that is being developed. Railroads should require vendors to produce a Human Systems Integration Program Plan (HSIPP) that details the HSI work that will be performed, how it will be done, and by whom, as part of the proposal submittal package. Requiring a vendor to produce an HSIPP is one of the best ways to help make sure they fulfill the HSI requirements (Hamilton, 2003) and other government agencies have already adopted this approach (DOD 2011; FAA 2009). An HSIPP contains, among other things, the following:

- *Overview Information*: An overview of the proposed system; preliminary concept of operations, associated human roles, and operational environment; experiences with predecessor systems, HSI program.
- *Organizational Information*: An organization chart of the vendor's primary organizational element(s) and primary HSI organizational element(s); summary job descriptions and the qualifications of key HSI practitioners.
- *Program Risks*: A discussion of how HSI risks that may contribute to technical, cost, or schedule issues will be identified and addressed.
- *Time-Phase Schedule and Level of Effort:* A milestone chart that identifies each HSI activity during the contract period of performance, including key HSI decision points and their relationship to the program milestones; the proposed number of HSI personnel on an annual basis.
- *HSI Program Quality Control:* An approach for periodically assessing the quality (relative success and progress) of the overall HSI effort and each HSI domain over the course of the contract.
- *HSI Participation in Analysis, Design, and Test & Evaluation Activities:* A set of specific HSI activities that will be performed as part of system analysis, design, and T&E, and how HSI considerations will be addressed within the broader system analysis, design and T&E process.

However, even if an HSIPP is required from vendors, it will not have the desired impact unless the railroads make it clear that HSI is important to them. An excellent way to convey the importance of this plan is to adequately weight the HSIPP as one of the evaluation criteria for winning the contract (INCOSE, 2015, p241). If HSI planning plays a key role in winning the contract, then vendors will plan HSI activities with an eye toward winning. This contributes to a more thorough and well-thought-out HSIPP which makes it easier for railroad acquisition staff to discriminate between which vendors have sufficient HSI knowledge and capability to do the job well and which do not. For example, a vendor that includes most of their HSI activities at the end of the SE process with little opportunity for HSI to inform design shows very little comprehension of HSI. A good HSIPP will integrate HSI early in the requirements analysis as well as the design and development stages, and it will continue to integrate HSI considerations throughout the SE process.

HSIPP Template. Because the authors believe that the front-end HSI planning by the vendors, and the RFP evaluation by the railroads, plays such an important role in determining whether adequate HSI will be done for a given project, this document includes a template to facilitate this process. Appendix E contains the template for an HSI Program Plan (adapted from DoD, 2011; FAA 2009) for vendors to complete and submit as part of the RFP package. Railroads can further adapt the template if their HSI practitioners believe that it would be helpful for a particular system.

1) The **Vendor** shall describe **HSI** activities in the **HSIPP**.

2) The **Vendor** shall prepare the **HSIPP** in accordance with the template provided by the **Procuring_Organization**.

3) The **Vendor** shall update the **HSIPP** at every milestone.

2.2.2 Integrating HSI Practitioners into the Systems Engineering Process

HSI practitioners should be members of the SE team, so they can apply their knowledge of (a) human capabilities and limitations, (b) related implications for system design, and (c) HSI analytic techniques to help identify and resolve human performance related issues that arise during the SE process. HSI practitioners should participate in all SE decisions that relate to human performance. They should take the lead in analysis, design and development, and T&E tasks that involve the design of system components where humans are involved. This includes the design of physical layouts such as workstations, seats, displays and controls in a cab; as well as the design of software user interfaces. Software design examples include new displays and also new forms of automation that may create new tasks or change the way users perform existing tasks. The HSI team is also responsible for coordinating with other engineering and design groups to make sure that system components that are not the direct responsibility of the HSI team, but have some human interfaces (e.g., they need to be maintained) also conform to human factors standards and guidelines.

To fully integrate the HSI process within the larger SE process, a well thought-out HSIPP should be developed and incorporated it within the larger SE program plan. Among other things, the vendor's HSIPP should include a chart that clearly defines the organizational structure of the HSI team, including roles and responsibilities, and describes the relationship between those with HSI responsibility and the rest of the SE team (as directed in the template in Appendix E).

4) The **Vendor** shall integrate the **HSI** program into the total **Systems_Engineering** process.

2.2.2.1 System Reviews

System reviews should begin early in the design and development process and continue throughout the process. These reviews identify risks and issues early in the design cycle when they are relatively inexpensive to fix. It is important that HSI practitioners participate in system reviews so they can identify and address human performance concerns that may arise. When issues are addressed early, the need for late-stages fixes to address performance problems is minimized and the need for training to compensate for design deficiencies is reduced.

5) **HSI_Practitioner(s)** shall participate in program, technical, design, and system reviews.

2.2.2.2 Integrated Product Teams

In many cases, the people working on the SE process are organized into integrated product teams (IPT). IPTs represent multi-function teams that provide multiple discipline and stakeholder perspectives in support of the product design. They effectively direct the product development process by resolving issues collaboratively across disciplines and stakeholders and enabling timely decisions that consider all critical angles of the process.

An IPT includes representatives from various specialty areas (e.g., program management, budgeting and finance, engineering, T&E, manufacturing, procurement, human factors engineering, training, maintainability) and should definitely include the HSI Lead (the person with overall responsibility for HSI activities and/or coordinating across HSI domains). INCOSE (2015) stresses the importance of including HSI practitioners as integral IPT members so they can identify human performance issues and provide advice on fixing them. This helps to ensure that systems will not require late-stages fixes to address performance problems due to poor design or expensive training to compensate for design deficiencies. The IPT should also include representatives from the procuring organization and user groups.

It would be wise for vendors to consider an IPT approach. Railroad HSI practitioners can expect to see discussion of the vendor's planned IPT, if any, in the HSIPP.

2.2.2.3 HSI Requirements

Ideally, the best practice would be to have the HSI practitioner involved in writing HSI requirements. At minimum, an HSI practitioner should be required to review the requirements, edit them as needed, and then approve them. If a HSI practitioner does not participate in the drafting and creation of HSI requirements, those requirements may be inaccurate, inappropriate, or otherwise problematic. And once the requirement becomes final, there is little an HSI practitioner can do to fix things during testing.

6) **HSI_Practitioner(s)** shall, at minimum, review, edit, and approve **HSI** requirements.

2.2.2.4 Sign off Authority

To facilitate the full participation of HSI practitioners with primary responsibility for HSI work and outcomes in a given area (as defined by the HSIPP), they should also have sign-off authority in that area. These specific sign off authorities should be designated in the vendor's HSIPP. Railroad acquisition staff should ensure that lead HSI staff have explicitly stated sign-off authority in the HSIPP for any area(s) of particular concern related to HSI.

7) The **Responsible_HSI_Practitioner** shall have sign off authority for each portion of the program's analysis, design and development, and **T&E** that involves a **Human-System_Interface** or impacts **Human_Performance**.

2.2.2.5 HSI Practitioner Qualifications

The HSI program should be performed by qualified practitioner(s) who are part of a team that is responsible for the HSI activities within the larger SE organization. To be qualified, an HSI practitioner needs to have relevant training and experience in one or more HSI domains.

As explained previously, HSI has multiple domains, including HFE, Training, Personnel, Occupational Health, and Safety. Each of these domains are practiced by separate professional disciplines with particular qualifications as well as appropriate training and experience.

The HSI team should contain one or more people that individually meet the professional qualification requirements of their respective fields, and collectively cover all the HSI domains that are relevant to the particular rail technology system development project.

While there are currently no HSI certification programs, there are a growing number of resources available for HSI training. Appendix D provides a list of programs that were available in 2015. It is recommended that at least one member of the HSI team have documented training in HSI or prior experience in conducting HSI activities within a system development project.

The exact composition, training, and experience requirements of the HSI team will depend on the specific rail technology system. HSI-fluent staff at the railroad should define the mix of training and experience qualifications that span the HSI domains relevant to the project. Appendix A of NUREG-0711 (2012) provides sample qualification requirements for the different HSI domains.

Regardless of the system being developed, one particularly important HSI domain is Human Factors Engineering (HFE). Boehm-Davis et al., (2015) define the HFE domain as "*Comprehensive integration of human capabilities and limitations (cognitive, physical, sensory and team dynamics) into system design, development and evaluation to optimize joint human-machine performance*." Knowledge of this domain is required to perform many of the required analysis, design and development, and T&E activities discussed herein (such as software interface design, understanding tasks and allocating functions, assessing workload, and conducting a final system validation study).

While there are several certification programs in HFE, including Board Certification in Professional Ergonomics, most qualified practicing HFE are not board certified. In practice, qualifications as an HFE are defined by educational degrees and relevant work experience. These include the following:

- Bachelor's degree (or preferably higher degree) in Psychology, Industrial Engineering, Computer Science or other related field along with a concentration related to HFE, such as human factors, engineering psychology or human-computer Interaction.
- Four or more years of cumulative experience related to the human factors aspects of systems design. Qualifying experience should include, at a minimum, participation in analysis, design and/or T&E of human-system interfaces.

If there will be multiple people responsible for HFE, the HFE team should meet these qualifications as a whole, and as many qualifications as possible should also be met by the HFE domain lead, the individual who will have primary responsibility for overseeing the HFE area and leading those engaged in HFE activities.

Ideally, one or more HSI practitioners on the team should possess knowledge and experience in HSI. This includes the following:

- Successful completion of at least one HSI training course and/or
- Two years of cumulative experience as an active member of an HSI team within a SE program.

Evaluators may want to select practitioners whose job experiences in HSI and human factors have been in organizations with an established record of HSI activities (e.g. DoD, FAA, NASA).

Alternative personal credentials may be acceptable as the basis for satisfying minimum qualifications specified for HFE or other HSI domains. Acceptance of such credentials should be evaluated on a case- by-case basis by the procuring agency and approved, documented, and retained by the vendor in auditable files.

The HSI Organization section of a vendor HSIPP (see template in Appendix E) should be used to help determine whether a vendor's HSI practitioners, those with HSI responsibilities, are qualified to do the work.

> 8) The **HSI** program shall be executed by **HSI_Practitioner(s)**.

2.2.3 Program Risk Management

Most programs contain risks that are associated with technical, cost, or schedule issues. A well-thought- out HSIPP acknowledges that risks may arise from human performance and human factors design issues, and establishes provisions to eliminate risks or reduce them to acceptable levels.[7] If risk management is considered early in the process, overall lifecycle costs associated

[7]Note that program risk management deals with identifying and managing risks that can jeopardize the success or schedule of a system development project, including risks associated with design of components that involve extensive human interaction. Safety risk management is a separate activity from program risk management. Safety

with training, staffing, or redesign should be limited. Therefore, early program decisions must reflect operator, maintainer, and support staff capabilities and limitations in order to avoid expensive training, staffing, or redesigns. Explicit consideration of user capabilities and limitations should occur during early analysis activities, including concept of operations development and functional requirements analysis. In addition, it is important that HSI risk be explicitly analyzed, documented, and addressed as part of the overall program risk management process.

9) The **Vendor** shall demonstrate consideration of **User** capabilities and limitations in **Concept_of_Operations** and **Functional_Requirements** documents.

10) **Program_Risk_Management** shall identify potential cost, schedule, design and performance risks that result from **HSI** design issues.

11) **Program_Risk_Management** shall analyze, prioritize and take actions to avoid, minimize, control, or accept each **HSI** risk.

12) **Program_Risk_Management** shall document and track each identified **HSI** risk, the impact of those risks, and the mitigation actions taken.

13) **Program_Risk_Management** shall include each **HSI** risk in the program's risk management process.

2.2.4 Traceability

Traceability refers to the ability to track initial HSI requirements – including operational objectives, constraints, and accompanying design implications – through the phases of the SE process to ensure that final system still meets these initial requirements (Pew and Mavor, 2007, pg. 305).

While traceability allows participants to understand how a design has been mapped to the initial requirements, it also shows how satisfaction of the requirement was established via T&E. Traceability helps maintain the established HSI objectives and constraints even as modifications are made to system design. It also facilitates tracking of instances where requirements are added, revised, subsumed, or eliminated as understanding of system objectives and constraints evolves over the course of the program.

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risk management deals with identifying and managing risks, including human performance-related risks that can impact the overall safety of a system once it is operational. See Section 2.3.5 for more on safety risk management.

14) **Vendor** documentation shall provide traceability from initial identification of **HSI** requirements through **Final_Verification** that these requirements have been met.

2.2.5 Operational Experts

Operational experts are individuals with direct knowledge and experience of the system's operational context. These are sometimes referred to as subject matter experts (SMEs). These experts must be included during analysis, design and development, and T&E activities to ensure that user goals, tasks, and performance challenges are adequately considered and supported. The selected operational experts should include individuals who are going to use the new technology to ensure that operational input is fully up-to-date (Evenson, Muller & Roth, 2008). Access to current target users can be a challenge as these individuals have day to day work responsibilities. Management support will be needed to make their time available and provide charge numbers for their participation. In addition, there may be challenges associated with scheduling time for their participation in analysis, design, and T&E events to accommodate demands of their regular work. This is simply pointed out as something management will need to consider in order to fulfill this requirement.

In some cases, the new technology may drastically change user roles and responsibilities or require entirely new roles and responsibilities. For example, new forms of automation may create new positions that combine work that was performed by multiple different individuals or involve entirely new tasks. Including individuals who accomplished similar functions prior to the introduction of the new automaton will allow the team to get their perspective on the operational environment and challenges that might impact performance with the new technology (Woods & Dekker, 2000).

15) **Operational_Experts**, including current target **User(s)**, shall actively participate in analysis, design, and **T&E** activities.

2.2.6 Railroad HSI Expertise

It is critical to examine the railroad's role in incorporating sound HSI practices into the development of their systems. The railroads, like the vendors, will need to acquire substantially more HSI and HFE expertise, either in-house or from contractors. Railroads need this expertise for at least three reasons:

(1) Railroads need to understand what the vendors are proposing when they respond to the RFP and they must be able to fully evaluate the quality of the HSIPP;

(2) Good HSI design also requires that stakeholders be involved in the process (e.g. major design reviews, tradeoff decisions);

(3) At the end of the project, one might ask: "If the railroads don't understand HSI, how will they know if they have gotten what they asked for?"

In other words, the railroads must stay engaged with the vendor's HSI process. At least one representative with HSI expertise from the railroad(s) should be involved throughout the acquisition and SE process. Additionally, those at the higher levels of program and organizational management should work on developing a basic understanding of HSI and why it is critical for good design outcomes and provide basic HSI training opportunities for their staff, particularly those involved with acquisitions.

Appendix F summarizes several resources for HSI courses and programs and it is a good starting point for those who wish to receive formal HSI training.

2.3 Analysis

A major part of SE is defining the system requirements, which specify the system characteristics, attributes, functions, and performance that will meet the stakeholder requirements (INCOSE, 2015, page 58). HSI activities specify the human-related system requirements that will be integrated within the full set of system requirements.

There are a number of analysis activities that contribute to defining human-related system requirements. These include activities intended to specify the following:

- *Concept of Operation* – What are the anticipated roles and responsibilities of user(s) in the system?
- *Operational Contexts and Use Case Scenarios* – What is the range of operational situations and complexities that need to be accommodated? What are use case scenarios that exemplify these complexities that can be used to inform system design and evaluation?
- *Human Performance Issues and Design Challenges* – Based on lessons learned from experience with predecessor and/or similar systems in other domains, what are the human performance concerns and design challenges that will require special attention in design and evaluation to minimize design risk?
- *User Functions and Tasks* -– What functions will the user(s) play in support of total system performance? What physical tasks will the user(s) need to perform? What cognitive and decision-making tasks will they need to perform? Can the user(s) perform these tasks within acceptable levels of workload and situation awareness?
- *Human Performance Contributors to Risk and Safety*– What are the critical human tasks that impact safety? How can the possibility of human errors with safety consequences be reduced? How can the potential for error detection and recovery be increased? What is required to enable the people in the system to recognize and mitigate the consequences of hardware and software failures?
- *Tradeoff Decisions*– What are the tradeoffs within and between HSI domains (e.g., cost of building an intuitive user interface vs. training cost implications of a less intuitive interface) as well as between the HSI and other SE elements (e.g., cost and schedule considerations) that need to be evaluated?

The output of these analyses lead to HSI requirements that inform design and development. These include user information and control requirements, requirements to support communication and coordination, and physical ergonomics requirements.

Note that HSI requirements need to be developed in tandem with other system requirements and integrated into the system requirements development process. HSI requirements continue to be refined and revised throughout the design and development process as new user needs are uncovered and/or system requirements are updated.

This section lays out HSI process requirements that are associated with analysis activities. Further readings, which provide more in-depth description of the analyses called out in this section and methods for conducting them, can be found in Appendix G.

2.3.1 Concept of Operation

An important early HSI activity is defining the Concept of Operation document. The Concept of Operation describes the characteristics of a proposed system from the viewpoint of the individuals who will use that system. The Concept of Operation is a high-level description of the objectives, roles and responsibilities of the users in the new (or redesigned) system. It is important to note that users include not only the system operators, but also the maintainers and the support staff that utilize the system in their work. For example, PTC system users include the train crews, who are the primary system operators, and the personnel who are responsible for maintaining and troubleshooting PTC equipment, such as equipment in the locomotive cab and equipment out in the field. In addition, PTC system users would include back office support staff that may be responsible for maintaining and updating databases that feed information to the PTC system (e.g., consist information) and Dispatch Center staff, who may be required to manually enter data (such as temporary speed restrictions) that impact PTC behavior.

The Concept of Operation is generally developed by a multi-disciplinary team which includes individuals with operational expertise in the relevant domain. Wherever possible, the team that develops the Concept of Operation should include current target users (e.g., currently operating locomotive engineers would be involved in the case of a locomotive cab redesign).

To develop a Concept of Operation, the team must first identify the stakeholder goals and requirements for the design or redesign of the system, with an emphasis on the role of the people in the system. Does the team want to:

- Reduce man-power costs by reducing the number of people required to operate the system?
- Reduce operating costs through improved resource utilization (e.g., reduce fuel costs)?
- Improve safety through reduced error?
- Improve performance by leveraging new technologies?

The multi-disciplinary team will provide a high-level description of how the system should function and cover the roles that the humans will play in the system. This description includes the role the human is anticipated to play under routine situations as well as under non-routine and emergency situations. The team must take into account stakeholder goals and requirements, an understanding of the operational context and challenges that the system will need to address, and a realistic assessment of available resources and technologies that can be brought to bear.

Colacioppo (2015) provides an example of a Concept of Operation for a new Integrated Service Information and Management (ISIM) system for New York City Transit. The concept of operation identified how the different people in the system (e.g., the train operator, the train dispatcher, the tower operator, the customer) were envisioned to interact with ISIM. Scenarios were developed for both normal operations as well as situations that deviated from normal.

> 16) The **Vendor** shall specify a **Concept_of_Operations** that describes the characteristics of the proposed system from the viewpoint of the **User(s)**.

2.3.2 Operational Contexts and Use Case Scenarios

Another important Concept of Operation activity is analyzing the operational environment and defining operational contexts and use cases to guide the analysis, design and evaluation of the system. Operational contexts are the range of operational situations and complexities that the system will be required to successfully handle. This includes routine operational contexts that should be straightforward for the system to handle as well challenging operational contexts that include complexities that are likely to challenge system performance.

Operational contexts include:

- Normal modes of operation (e.g., starting up the system; use of the system when in route; use of the system within stations, yards or terminals; testing the system; shutting down the system);
- Conditions that may challenge the performance of the human user and/or other components of the system (e.g., the automation), including:
    - Physical and environmental conditions (e.g., weather that might impact visibility; sharp changes in terrain grade);
    - Situational conditions (e.g., traversing across territories with different sensors, equipment or rules of operation);
    - Degraded modes of operation (e.g., degraded or failed sensors; electronic communication interference; automation failures)
    - Emergency modes of operation (situations that require actions to be taken to avoid or mitigate damage to equipment or harm to people, such as a need for rapid action to avoid a derail or collision).

Use case scenarios illustrate the range of operational conditions and complexities that the system needs to handle. A railroad use case scenario might be a situation where a long heavy freight train drives up a steep grade in the rain or snow with a requirement to reduce speed toward the top in order to satisfy a speed restriction zone. The steep grade and rain or snow are factors known to pose train handling challenges.

These scenarios typically identify actors, contextual situation, information requirements, decisions (induction or deduction), time constraints (available or required), and so on. During the design process, use case scenarios can help the team understand how the users would interact with the system hardware and software in that scenario. The same scenarios can be used during evaluation to establish that users can in fact perform the required tasks under the challenging conditions defined by the scenario.

The operational contexts and use case scenarios should go beyond the use cases for typical or intended system operations. The goal is to define a range of realistic conditions, include situations that are known to be challenging, and describe situations that illustrate what could go wrong (such as system failures and emergency conditions) and how those would be successfully handled. The scenarios should span the range of tasks that the users will need to perform, and the variety of cognitively and physically challenging conditions they will need to operate under.

Operational contexts and use case scenarios are used to:

- Derive design requirements;
- Communicate to users and other stakeholders how the design should work under a range of typical and challenging situations; and
- Develop test scenarios to be used during system evaluations, particularly the user-in-the loop validation tests.

New York City Transit developed scenarios that represented both normal and deviations from normal scenarios to guide design of their new ISIM system (Colacioppo, 2015).

The operational contexts and use case scenarios should be developed by an interdisciplinary team that includes operational experts and current target users who can identify the range of real-world conditions and complexities that the system will have to handle. It is important to establish buy-in from stakeholders, and most particularly from current target users, that the set of identified operational contexts and scenarios are representative of the range of conditions and complications that can realistically arise.

When a system is designed, it is important to ensure that it supports the ability of personnel to perform critical human tasks. A critical human task is defined as "a task requiring human performance which, if not accomplished in accordance with system requirements, will likely have adverse effects on cost, system reliability, efficiency, effectiveness, or safety. A task is also considered critical whenever equipment design characteristics demand human performance which approaches the limits of human capabilities" (FAA, 2009).

When operational contexts and use cases are analyzed, critical human tasks should be explicitly addressed, as well as the operational contexts that could challenge the performance of these critical human tasks. It is important to identify human performance issues with safety implications and their associated risks early. This includes both cases where human actions or failure to take action can contribute to risk as well as cases where human actions are required to prevent or mitigate risks (e.g., risks due to equipment malfunctions or failures).

Critical human tasks and the operational contexts that could challenge the person(s) performing the tasks should be included as part of the use case scenario set used to define design requirements as well as test scenarios to be used in system evaluation, particularly the final system validation.

It is important to stress that analyses of critical human tasks, operational contexts and use case scenarios should address all users of the system, including the primary system operators and maintainers and support staff upon which the performance of the system depends.

17) The **Vendor** shall provide a range of **Use_Case_Scenarios** that include routine operational contexts as well as challenging operational contexts as input to design requirements, design demonstration, and **T&E**.

18) The **Vendor** shall identify **Critical_Human_Tasks** for operational, maintenance, and support activities.

19) **Use_Case_Scenarios** shall include **Critical_Human_Tasks** and operational contexts that challenge **User(s)**.

2.3.3 Lessons Learned Review

Another analysis activity that is used to derive system requirements for human performance is a lessons learned review (called an "operating experience review" in NUREG-0711, Rev. 3). The purpose of a lessons learned review is to leverage prior experience to identify human performance concerns and design challenges that will require special attention in design and evaluation so as to reduce the risk of a poor design and ensure that the final system will be able to be operated, maintained, and supported, safely and efficiently.

Lessons learned reviews are based on experiences with predecessor systems and experiences with similar systems implemented in other domains. The goal of a lesson learned review is to identify human performance issues and design challenges that will need to be addressed as part of design and evaluation of this system. Such design challenges include:

- Alarm fatigue, where systems generate too many false alarms or non-actionable alarms that serve as a source of distraction and result in users ignoring or even in some cases disarming the alarms
- Automated systems that are not trusted and so are not used when they should be
- Automated systems that are over-relied upon and followed under conditions where the automation should have been turned off or over-ridden.

Lessons learned reviews can also point to design solutions that have proved successful in other domains that can be adopted in the design of the present system.

These reviews include:

1. Examine experiences with the previous system (e.g., review of human performance and design problems that exist with current train cab designs that the new design should avoid or mitigate);
2. Examine design issues and solutions associated with similar technologies that have been introduced into other domains (e.g., introduction of automation in the aviation and other transportation domains such automotive technology).

When the performance of predecessor systems are reviewed, some of the following activities could include:

- Reviews of accident or near-miss databases
- Working with focus groups with operational and maintenance users of the predecessor system
- Collecting field observations and interviews conducted in the operational context.

Examples of lessons learned reviews that inform design in the railroad industry are available in the literature. They include a review of operating experiences with early implementation of PTC systems in selected railroads to identify human factors issues that emerged and how they might be addressed (Roth & Multer, 2009); and a review of the roles and responsibilities of freight railroad conductors in today's environment with implications for how PTC may impact train crew roles and responsibilities in future operation (Rosenhand, Roth & Multer, 2012).

Lessons learned reviews may draw on anonymous reporting systems and/or confidential interviews, where individuals can describe system factors that promote error or require unsafe work-arounds without facing penalties or disciplinary action. When the review covers experience that occurred in related domains, it may use HSI literature reviews as well as site visits and interviews with individuals who have operational and/or engineering design experience in these related domains.

One example of a railroad-related lessons learned review that synthesized experience in related industries is in Sheridan, Gamst and Harvey (1999), which reviewed the effects of automation on reliance and distraction in non-railroad industries to inform design of PTC systems. Another railroad-related lessons learned review is in Wreathall, Woods, Bing and Christoffersen (2007), where human factors issues associated with workload/workmode transitions involving technologies similar to PTC were reviewed to identify potential issues of concern associated with the PTC mode transitions that may arise when a train traverses across multiple railroad territories that have different PTC implementations.

When a lessons learned review is finished, it should be able to a set of human performance issues, as well as potential design solutions, to the system design and evaluation process. In particular, the set of human performance issues identified by the lessons learned review should feed into the development of operational contexts and use case scenarios, particularly test scenarios to be used in evaluations and final system validation study. (More on final system validation in Section 2.5.5.) The lessons learned review is more in-depth than the preliminary discussion of predecessor systems and lessons learned that vendors are asked to provide as part of the HSIPP. (See Appendix E, part 2b-3.)

20) The **Vendor** shall conduct **a Lessons_Learned_Review**.

21) The **Lessons_Learned_Review** shall include a review of operating experience with predecessor systems.

22) The **Lessons_Learned_Review** shall include a review of similar systems in other domains.

23) The **Lessons_Learned_Review** shall identify **Human_Performance** issues and design challenges requiring special attention in design, evaluation, and **Final_System_Validation** of the system.

2.3.4 Assignment and Detailed Understanding of Tasks

In the HSI process, a set of activities are used to develop a detailed analysis of the cognitive and physical tasks that system users will need to perform.[8] This analysis includes:

- the functions that people are expected to perform within the system
- the operational tasks they will need to perform using the new hardware and software (e.g., operating the train using the new technologies)
- the tasks they will need to perform to interact with the hardware and software (e.g., computer interaction tasks to initiate, setup or cut out an automated system)
- other tasks they will need to perform in parallel outside of that specific hardware or software (e.g., monitoring out the window to identify hazards on the track).

The analyses need to identify the following:

- New tasks (e.g., entering consist information into an automated train control system);
- Tasks that used to be performed that will no longer need to be performed (e.g., a system that provides automatic alerts to upcoming speed restrictions eliminates the need for conductors to remind locomotive engineers of upcoming speed restrictions); and
- Tasks that changed because of the new hardware or software (e.g., locomotive engineers may need to follow the braking profile of a new automated train control system to avoid automatic penalty brakes, which means new train handling approach).

The output of these analyses are used to do the following:

- Establish that the assigned tasks are within the mental and physical limits of the user(s);
- Define the display and control elements that will need to be designed to support the tasks;
- Define associated operating rules and procedures;
- Define the training requirements; and
- Identify personnel selection requirements

Understanding the distribution of mental and physical workload across activities and team members is particularly important. For example, it is important to ensure that the planned complement of operating crew will be able to accomplish all required tasks within acceptable levels of workload.

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[8]In this and all following sections, 'user(s)' is intended to refer not only to the primary system operators but also the maintainers and support staff upon which the performance of the system depends.

There are multiple types of analyses that define user functions, delineate cognitive and physical tasks, and associated workload. The key ones are function analysis and allocation, task analysis, and workload and situation awareness analyses.[9]

- **Function analysis and allocation** is usually performed first. In this activity, the functions that a system must perform to achieve its objectives are identified and described. Then the team determines how they can be best allocated (to people, hardware, software, or a combination of them). From the HSI perspective, this activity helps system engineering understand how functions can/should be automated, grasp the implications of automating a person's role in the system, and recognize their information and control needs. For example, if functions that are normally performed by a person become automated, then the user becomes a supervisor of automated functions. This requires displays that allow the user to maintain situation awareness of what the automated software is doing, why the software is doing it and what the software will do next, so that the person can be in a position to adjust, cutout or manually over-ride the automation in cases where the automation fails or is outside the boundaries of its area of competence.

  Function allocation covers assignment of functions to people, software or hardware and the assignment of functions across people, which is often referred to as team design. One of the early system design decisions involves staffing, or determining how many people will be required to support system performance. For example the Concept of Operation may specify train crew size and the roles and responsibilities of train crew members. Function allocation, task analysis and workload analysis ensure that all required cognitive and physical tasks can be performed within acceptable workload levels. If analyses suggest that the required functions cannot be achieved with the specified level of staffing, then the Concept of Operation may need to be revised. This is an example of the iterative nature of the analysis and design process.

- **Task analysis** provides a detailed breakdown of the tasks needed to accomplish the functions assigned to people across the range of operational contexts. There are a variety of traditional task analysis methods (including hierarchical task analysis) that can be used to specify the tasks to be performed, the steps involved, and the information and control requirements (Kirwan & Ainsworth, 1992).

  Traditional task analysis methods work well for tasks that are primarily physical and occur in a clear sequence. Examples may include following an ordered set of steps that direct a series of actions required to initiate a system.

  Traditional task analysis methods are less appropriate for work that is primarily cognitive in nature (e.g., involving monitoring, maintaining situation awareness, communicating, planning and decision-making). In these tasks, individuals must juggle multiple competing goals and tasks, resulting in highly non-sequential task performance. Operating a train is an example of a dynamic, highly cognitive task. Train crews need to simultaneously monitor out the window, communicate with dispatchers and roadway workers, operate the train, blow the horn, comply with operating rules, and make

[9] Workload is the physical and mental (cognitive) demands that tasks place on users of a system. Having situation awareness is being aware of the elements of the immediate environment, comprehending implications, and being able to anticipate what is coming in the future. Both of these are discussed in greater detail later in this section.

moment-to-moment decisions as to which task to perform and what to prioritize. For cognitive-oriented work, cognitive task analysis and cognitive work analysis methods are more appropriate to use to identify the cognitive demands of the work, the information, decision-support and control requirements, as well as the knowledge, skill and training requirements. For example, cognitive task analyses can produce an information inventory that identifies the information elements that are required to support operational user/maintainer decision making.

There are a variety of cognitive task analysis and cognitive work analysis methods that can be used to support identification of human-related system requirements to guide design and evaluation. Cognitive task analysis methods tend to rely on observation and interview techniques to understand the nature of the work and its cognitive challenges. Overviews of cognitive task analysis methods and their use in defining HSI requirements can be found in Bisantz and Roth (2008), Crandall & Hoffman (2013), and Endsley (2015). Cognitive Work Analysis methods provide a comprehensive framework to systematically analyze the characteristics and requirements of work. These methods begin with an analysis of the goals, constraints and capabilities of the system that will affect how the operator works (a work domain analysis) and follows with a series additional analyses intended to derive not only information and control requirements, but also requirements for communication and collaboration, teamwork design, and training. Overviews of cognitive work analysis methods and how they can be used in defining HSI requirements can be found in Roth and Bisantz (2013) and Stanton and McIlroy (2015).

The literature contains documentation which explains how cognitive analysis methods have been used in the railroad industry to derive display and decision support requirements. For example, Tappan, Pitman, Cummings and Miglianico (2011) used cognitive task analysis to derive display requirements for an interactive in-cab rail scheduling display. Millen, Edwards, Golightly, Sharples, Willson and Kirwan (2011) used cognitive work analysis methods to identify the cognitive demands associated with train dispatching and how these are impacted by changes in user interfaces and automation. Subrahmaniyan, Liu, Miller, Groshong and Brooks (2014) used Cognitive Task Analysis and Cognitive Work Analysis methods to identify the cognitive activities of locomotive engineers, conductors, and railroad dispatchers and derive metrics that could be used evaluate alternative human-automation task allocation. The methods and visual representations in these examples can serve as models for informing a design with a cognitive analysis.

- **Workload and Situation Awareness analyses** must also be considered. Workload is the 'relationship between the resources required to carry out a task and the resources supplied by the operator (Wickens and Tsang, 2015). By this definition, resources can include time available to perform the task, as well as mental and physical resources required for acceptable task performance. Whereas workload can be characterized as "the amount of cognitive or attentional resources being expended at a given point in time," situation awareness is "the momentary content of those resources, a subjective state that is afforded by the object or objects of one's attentional resources" (Charlton, 2002). Situation awareness is often also defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future (Endsley, 1995, pg. 36).

The concepts of workload and situation awareness are both important for operator performance in the rail environment. If new technology introduces excessive physical or mental workload demands or sudden shifts in workload demands, then performance can degrade (Wreathall, et. al., 2007). Similarly, maintaining an accurate situation model of the immediate environment and anticipating what is coming ahead (i.e. situation awareness) is one of the major cognitive challenges involved in operating a train (Roth & Multer, 2007). If new technology places excessive attention demands inside the cab, it may disrupt the ability to maintain situation awareness of objects and events in the outside environment.

There is also a need to ensure that new automation does not lead to complacency – an over- reliance on automation that results in a loss of situation awareness while operating the train (Sheridan et al., 1999). For example, fuel optimization systems are now available that can do much of the train handling for the engineer, thus reducing his/her workload. The authors have heard anecdotal reports that some engineers who use these systems are less mentally engaged as a result, indicating to us that situation awareness may be reduced when this technology is in use. It is important that train crews remain engaged and situationally aware so that they are able to detect and rapidly respond to system malfunctions or other unanticipated events.

In addition to any workload and situation awareness assessments that inform the design process, both workload and situation awareness must be assessed during final system validation. (Section 2.5.5 includes the requirement to assess workload and situation awareness during final system validation.) There is flexibility when choosing the type of metric for both these constructs.

A variety of analytic and empirical methods are available for estimating workloads. There are three broad types of empirical techniques for collecting mental workload data: (1) performance- based measures (collecting performance data on tasks of interest), (2) subjective measures (asking participants to make estimates based on established rating scales) and (3) physiological measures, such as pupil diameter, eye-blink rate, brain imaging (e.g. through functional magnetic resonance imaging fMRI), etc. (Charlton, 2002; Pew & Mavor, 2007; Phuong & Chiappe, 2015; Wickens & Tsang, 2015).

Empirical measures of workload are typically used in T&E. There are also analytic methods for predicting workload, including simulation models. Analytic approaches have an advantage because they can generate predictions of workload before highly detailed user interface designs are available. As a consequence, they can be used in the early part of the system development process to anticipate likely impact on workload of alternative design concepts (Charlton, 2002).

Workload assessment can evaluate the performance or safety of a system, compare alternative system designs, and help identify and mitigate sources of too high or too low workload (e.g., due to non-optimal operator strategies, inadequate training, or poor user interface). Wickens and Tsang (2015) provide an overview of methods for measuring workload and strategies for identifying and mitigating unacceptable levels of workload.

Similarly, a variety of techniques have been developed for measuring situation awareness (See Wickens, 2008 and Tenney & Pew, 2006 for recent reviews.). Measures of situation awareness include the following:

- Recall measures, that require participants to answer questions about a dynamic situation with the display blanked out;
- Critical event techniques that measure how quickly individuals detect and respond to critical events inserted in a dynamic scenario;
- Self-rating assessments of situation awareness where test participants are asked to evaluate their situation awareness using rating scales; and
- Expert judgment techniques, where SMEs are asked to evaluate the situation awareness of test participants based on observation of their performance.

Think-aloud protocols (where the participant verbalizes their thoughts while engaged in a task) can also be useful for assessing situation awareness early in system development (Pew and Mavor, 2007). The critical thing to understand is that there is no one best method for evaluating neither workload nor situation awareness. Different metrics are better suited for particular objectives (Charlton, 2002; Wickens & Tsang, 2015). Reviews are available elsewhere discussing the different methods available and how to select the most appropriate one for a specific evaluation (e.g., Charlton, 2002; Gawron, 2008; Phuong & Chiappe, 2015; Wickens & Tsang, 2015; Tenney & Pew, 2006; and Wickens, 2008).

An important consideration in design and evaluation of a system is to ensure that critical human tasks are adequately supported. Critical human tasks are defined in Section 2.3.2. Task and workload analyses should explicitly include analysis of critical human tasks and situations. It is important to identify early human performance issues with safety implications and their associated risks. This includes both cases where human actions or failure to take action can contribute to risk as well as cases where human actions are required to prevent or mitigate risks (e.g., risks due to equipment malfunctions or failures).

Critical human tasks should be analyzed in detail, including the potential for and consequences of human error as well as potential for error recovery**.** The analysis should be performed for all operational modes including degraded and emergency modes of operation. Each critical human task should be analyzed to a level sufficient to identify operator, maintainer, and support staff problem areas that can adversely affect mission accomplishment, and to evaluate proposed corrective action(s).

The results of task analyses, including cognitive task analyses, and workload and situation awareness analyses can be used to inform hardware and software design, particularly user interface design. The output of these analyses can also feed into other HSI domains including identification of manpower requirements, particularly requirements for team size and composition, procedures, training, and communication, and logistics support requirements. Often times procedure and training are done by different groups. The output of tasks analysis, related cognitive analyses, and workload analyses should be made available to these groups.

As in other aspects of HSI, task, workload, and situation awareness analyses are iterative processes. Initial task, workload and situation awareness analyses may be done at a high level, with details filled in, as more information is collected and the design matures. Results of task, workload, and situation awareness analyses and implications for design requirements should be iteratively revisited and refined, and documentation updated as analysis and design activities proceed. Any human performance or workload issues identified by the analysis and test process should be mitigated through appropriate corrective action (e.g., design changes, changes in task allocation, changes in training).

24) The **Vendor** shall use **HSI_Methods** to analyze the functions assigned to humans within the system.

25) The **Vendor** shall use **HSI_Methods** to identify the cognitive and physical tasks, including requirements for maintaining **Situation_Awareness**, and the **Workload** associated with the functions assigned to humans within the system.

26) The **Vendor** shall analyze **Critical_Human_Tasks** to identify conditions that can adversely affect the ability of the **User(s)** to accomplish the task in accordance with system requirements.

2.3.5 Safety Risk Analysis and Management

SE typically includes processes for analyzing and managing safety risks. It is important to ensure that human performance risks are included in the program's safety risk management process. The objective is to ensure early identification, understanding, and control of risks that either arise from problems in human performance (e.g., human errors) or that require human action to mitigate consequences of hardware or software failures (e.g., the need for a person to over-ride a spurious automated braking response that might cause a derailment). A systematic approach should be used to analyze, assess and mitigate human performance issues that contribute to safety risk.[10] The results of the analyses are used to identify HSI requirements and reduce the possibility of human error, increase the potential for error detection and recovery, and increase the ability of the people in the system to recognize and mitigate the consequences of hardware and software failures.

27) The **Safety_Risk_Management** process shall include **HSI** risks.

28) The **Vendor** shall use a systematic approach to analyze, evaluate, and mitigate **Human_Performance**-related risks that can impact the overall safety of the system.

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[10] Note that safety risk management is a separate activity from project risk management. Safety risk management deals with identifying and managing risks, including human performance-related risks that can impact the overall safety of a system once it is operational. Program risk management deals with identifying and managing risks that can jeopardize the success or schedule of a system development project, including risks associated with design of components that involve extensive human interaction. See Section 2.2.3 for more on program risk management.

2.3.6 Tradeoff Analyses

There are times when major design decisions must be made within HSI domains, between HSI domains, and/or between HSI and other SE elements (such as costs, schedule) and the best alternative is unclear. An alternative that is optimal in one or more ways may also have one or more drawbacks in other areas; tradeoffs must be made to select the option that will best meet program needs. For example, the HSI domains of Human Factors Engineering and Training could suggest different approaches if designing a more intuitive user interface will be more costly to build, but will result in reduced training time and thus reduced training costs.

Tradeoff analyses may be addressed in formal tradeoff studies. The magnitude, scope, and type of analysis done will depend on acquisition phase, system complexity, as well as cost and time constraints (FAA, 2009). There is some flexibility in how tradeoff analyses are accomplished but it is critical that tradeoffs are fully considered so that the decisions made achieve system requirements. The primary goal in any kind of tradeoff analysis is to optimize human performance to support capability and performance requirements for the total system and minimize lifecycle cost. The vendor's HSIPP should clarify what they see as the major tradeoff decision points and how they plan to address them. (See Appendix E, Section 2i on *HSI Support of Affordability and Performance Goals*).

29) The **Vendor** shall consider and address tradeoffs among **HSI_Domains**.

30) The **Vendor** shall consider and address tradeoffs between **HSI** and other software and hardware factors.

31) Tradeoff analyses shall consider the **Human_Performance** impact on total system performance and life cycle cost.

2.3.7 Requirements Implications

The output of the analyses described above lead to HSI requirements that inform design and development. Output requirements include:

- *Information and Decision Support requirements* – Defines the information that will need to be provided to the user and describes what form does it need to take to support performance
- *Control Requirements* – Defines the controls and modes of interaction that will be needed to enable the user to take appropriate action
- *Communication and Coordination Requirements* – Determines who the users must communicate and coordinate with and describes the methods for communication
- *Physical Ergonomic Requirements* – Describes the physical requirements, including layout, lighting and environmental requirements that will be needed to support performance

HSI requirements need to be developed in concert with other system requirements and integrated into the system requirement development process. They continue to be refined and revised throughout the design and development process as new user needs are uncovered and/or system requirements are updated.

2.4 Design and Development

The design and development process generates specific hardware and software designs that meet system requirements. Often, this involves identifying and evaluating alternative ways (combinations of hardware, software and people) to create the desired system functionality. HFE is the HSI domain that deals with design and development of hardware and software.

During design and development, HSI requirements are generated using stakeholder inputs and HSI analyses are converted into detailed design features. The HSI requirements are continuously revised and refined throughout the design and development process, because the design process itself generates a better understanding of the user's goals, tasks and performance challenges. In turn, this results in new or refined requirements (Evenson, Muller & Roth, 2008). Thus, there is an iterative feedback loop between design and requirements specification with requirements continuing to be refined as the design matures.

HSI design applies to the design of the physical work environment in which user activity will take place (e.g., the locomotive cab) and the user interfaces of software components with which users will interact (e.g., train fuel optimization software).

There are a number of design and development activities that contribute to converting HSI inputs into detailed design features:

- *Work Environment Design* – Designing work environments and facilities to ensure personnel performance, comfort, health and safety
- *Human Computer Interface/Software Design* – Designing the overall architecture/structure of the software as well as the particular software components that require human interaction to ensure efficient and safe performance under normal, degraded and emergency conditions.
- *Design of Procedures, Manuals, and Documentation* – Developing procedures, training manuals and related operations and maintenance documentation and ensuring that they are readable, understandable and usable under operational conditions.
- *Application of Human-Computer Interaction Guidelines and Standards* – Ensuring that hardware and software designs meet established standards and guidelines
- *Participation in Design and Review of Systems and Subsystems* – Ensuring that all system components are safe and usable by including HSI practitioners in a review and advise capacity of all systems that involve a human-system interface

As noted earlier, the design process is necessarily an iterative process that involves tight design and user feedback loops, involving design and test of prototypes of increasing degree of fidelity until an acceptable solution is achieved. Section 2.5.2 in the T&E section provides more details on the prototype development and user review and evaluation process.

2.4.1 Work Environment Design

When work environments and facilities are designed, the following factors are taken into consideration, as applicable, to ensure personnel performance, comfort, and occupational health and safety, under normal, degraded, and emergency modes[11]:

a. Adequate physical, visual, and auditory interfaces between personnel and their equipment, including provision for proper eye position in relation to display surfaces, controls, and external visual areas;
b. Provisions for addressing the effects of atmospheric conditions, such as temperature, humidity, and air flow;
c. Provisions for minimizing the effects of weather and climate, such as rain, hail, snow, ice, and mud, as well as desert and arctic conditions;
d. Protection from physical and performance effects of acoustic noise (steady state and impulse), vibration, and impact forces;
e. Adequate space for personnel, their movement, and their equipment, including job aids;
f. Safe and efficient walkways, stairways, platforms, and inclines;
g. Provisions for minimizing physiological and psychological stresses;
h. Provisions for minimizing fatigue;
i. Allowance for the effects of clothing and personal protective equipment, such as gloves, masks, and cold weather clothing;
j. Equipment-handling provisions, including remote handling provisions and tools when materiel and environment require them;
k. Provisions for safe and error-proof equipment installations;
l. Protection from chemical, biological, toxicological, radiological, thermal, mechanical, electrical, electromagnetic, and directed energy hazards;
m. Adequate illumination commensurate with anticipated visual tasks; and
n. Adequate space, clearance, and layout for normal ingress and egress and emergency escape from workstations and facilities.

References that provide more information on principles and methods for design of work environments and facilities are in Appendix G.

32) The **Vendor** shall apply **HSI_Methods** to detailed design of **User(s)**' physical work environments.

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[11] The list of factors to be considered in work environment design is taken directly from HF-STD-004 (2009) pgs. 18 and 19.

2.4.2 Human Computer Interface/Software Design

Software components that require user[12] interaction should be designed in accordance with established HSI design methods and principles to ensure efficient and safe performance under normal, degraded and emergency modes. HFE specialists should take the lead in specifying the look, feel, and content of controls and displays, and they should participate in software architecture and design decisions that impact human performance. There are a variety of established HFE and human-computer interaction methods and design principles that are available to support design of software systems that involve user interaction (Burns & Hajdukiewicz, 2004; Bennet & Flach, 2011; Endsley & Jones, 2012: Evenson, Muller & Roth, 2008; Shneiderman, Plaisant, Cohen & Jacobs, 2010; Sarter, 2013).

Software should be designed to:

- Support efficient interaction
- Provide access to required information in a form that supports accurate and timely decisions and actions
- Minimize attention requirements and workload associated with interacting with the software
- Minimize the potential for human error
- Support error detection and recovery

Particular focus should be placed on ensuring effective design of human-computer features and components that have been shown to create human performance challenges. Examples include the following:

- Design alarms to minimize the potential for false alarms, non-informative alarms, and non- actionable alarms that create distraction
- Design multifunction controls and displays that vary in function depending on system state to minimize human errors due to mode confusion
- Design automated system functions that require human monitoring or intervention so as to reduce performance problems including complacency and over-reliance at one extreme and lack of trust in the automation and disuse at the other extreme

References that provide more information on principles and methods for the design of software and hardware that require human interaction are in Appendix G.

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[12] Users include any individuals which utilize the system in their work, including system operators, maintainers, and support staff.

33) The **Vendor** shall apply **HSI_Methods** to the design of software systems that require **User(s)** interaction.

34) The **Vendor** shall apply **HSI_Methods** to the design of hardware that require **User(s)** interaction.

2.4.3 Design of Procedures, Manuals, and Documentation

HSI practitioners should also participate in developing procedures, training materials, and operations and maintenance documentation. If HSI practitioners participate, the material will be more complete, accurate, and more easily understood and followed. As with design of software and hardware, it is important to ensure that the content and form of the presented material minimizes the possibility of human error and provides opportunity for error detection and recovery.

The HSI analysis, design, and evaluation activities used for hardware and software also apply to the development of procedures, manuals and documentation. Considerations include the following:

- Thoroughness of coverage
- Technical accuracy
- Suitable format for the information
- Reading level and technical sophistication appropriate to the user
- Clarity
- Quality of illustrations

35) The **Vendor** shall apply **HSI_Methods** to the development of all electronic and hard-copy documentation.

36) The **Vendor** shall apply **HSI_Methods** to the development of all electronic and hard-copy training materials.

2.4.4 Meet Human-Computer Interaction Guidelines and Standards

Hardware and software designs should conform to established standards and guidelines for human- computer interaction, which helps ensure that the physical and cognitive user requirements are accommodated in system development. The requirements should also support system-wide standardization of human-systems interfaces. There are currently multiple standards and guidelines developed by various government, professional and industry groups. For example, one of the most comprehensive HSI standards documents is DOD-MIL-1472. (The latest version is DOD-MIL-1472G, which was published in 2012.) Most standards and guidelines are periodically updated to reflect emerging research and technology developments.

To use established standards, the vendor's or procuring organization's HSI practitioners must first identify the relevant standards for hardware/software and decide which ones to use. However, even if a good standard is selected because it applies to the project, some tailoring may be needed to meet the needs of the specific program. For example, MIL-STD-1472, which is excellent, also includes much material that is only relevant to military applications. Therefore, if using this standard, the vendor or the procuring organization would ask their HSI team to tailor it by identifying which portions of the standard that apply and which portions do not apply. Documented justification should be provided for portions of the standard that do not apply.

Tailoring may be more than deciding which sections of a standard do and do not apply to a project. It can involve determining if any "shoulds" (recommendations) should be changed to "shalls" (requirements) or vice versa, creating new requirements where needed, editing language where needed to ensure requirements are verifiable (more on verification in Section 2.5.4), and removing redundant requirements (Appendix C of FAA, 2009). In all cases there should be clear documentation that justifies the changes that are made. Those individuals tailoring requirements may find INCOSE (2012) and FAA (2009, Appendix C) useful.

HSI teams often ensure that selected and tailored design standards and guidance by developing a system- wide style guide, which also ensure that there is consistency in look and feel across all system user interfaces. A style guide can incorporate all applicable standards and guidance and create a specific look and feel convention for user interfaces. Standardization is then enforced by requiring that all user interfaces system wide adhere to the style guide.

2.4.5 Participation in Design and Review of Systems and Subsystems

HSI practitioners should take the lead when the project designs and develops physical components (e.g. locomotive cab design) and software components (e.g., user interfaces) that involve heavy interaction with users. There will also be components that may not involve heavy user interaction, but may nevertheless involve some user interaction. Examples include equipment that does not require user interaction for operation but may require user interaction during test and maintenance. For those system components, it is important that HSI practitioners participate in the design and development process in a review and advise capacity.

HSI practitioners must fully participate in any system reviews that involve a human-system interface. It's important to make sure that any critical Human Engineering Discrepancies (HEDs)[13] identified during review are addressed before progressing to the next design and development phase and this can only be done with the participation of those with HSI expertise. HED identification, tracking, and resolution are described more fully in Section 2.5.3.

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[13] A human engineering discrepancy (HED) is any HSI-related deficiency that contributes to human performance problems. This includes aspects of the design, procedures, or training that do not fully support personnel task requirements; that contribute to excessive workload or distraction; that induce human error or do not support recovery from human error; and/or that create risks to health or safety. HEDs are discussed more in Section 2.5.3.

37) **HSI_Practitioner(s)** shall participate in design reviews and engineering change proposal reviews of each system component that involves a **Human-System Interface**.

2.5 Test and Evaluation (T&E)

T&E activities happen throughout system development. Initial evaluations may take the form of informal reviews with users and stakeholders. As the design matures and rapid computer-based prototypes become available, HSI practitioners can conduct more formal user tests where qualitative observations, quantitative performance data, and user feedback can identify design deficiencies that need to be addressed in later design cycles. By doing these kinds of early T&E activities, issues can be identified and resolved early in the system engineering process when they are much less costly to fix. Once the design is completed and ready for acceptance testing, HSI practitioners should conduct a more formal and comprehensive final system validation that includes human-in-the-loop testing and uses a range of realistically challenging operational scenarios. This ensures that the final integrated system complies with the system requirements and meets operational performance and safety objectives.

This section focuses on T&E activities occurring throughout the SE process, with an emphasis on final system validation. It includes the following issues:

- *T&E Planning* – What must be done to facilitate T&E planning and what information must be included, at minimum, in a test plan?
- *Rapid Prototypes and User Reviews/Evaluations* – Why is rapid prototyping important and why do current target users need to be included in the evaluation process?
- *Human Engineering Discrepancy (HED) Resolution* – How can HEDs (i.e., HSI-related design deficiencies) be identified correctly, tracked, and resolved? What kinds of HEDs must be corrected?
- *Final System Validation* – What is final system validation? Who are the participants used in this testing? What kinds of tasks must they do and under what conditions?
- *Workload and Situation Awareness* – What are they and why is it important to assess them?
- *Evaluation Staff* - Who oversees T&E activities? And what limitations are there on who can be part of the final verification and validation team?

2.5.1 T&E Planning

T&E activities play a critical role in producing a system design that meets user needs; however, advance planning must be done to ensure that it is done well. Just as with other aspects of the SE process, HSI- related T&E activities must be incorporated into the larger set of SE T&E activities.

38) The **Vendor** shall incorporate **HSI** testing into the system **T&E** program.

T&E activities are critical because they start early in the system engineering process and they inform design (something that will be further discussed in Section 2.5.2). However, these early T&E activities also help to plan subsequent T&E activities.

At the most basic level, T&E can be used: (1) as a formative evaluation, used to inform design and (2) as a summative evaluation, used to validate that the final system meets requirements. Formative T&E activities also help plan subsequent T&E activities.

Prior to each evaluation, a test plan should be written that specifies the test objectives, test methods, the data to be collected and how it will be analyzed to draw conclusions (O'Brien and Malone, 2002). There is a great deal of information that can be included. The requirement below includes a bare minimum that is applicable across the board and the authors expect that vendor's HSI practitioners will include more information as appropriate. Additionally, if the test plan is for a summative evaluation, i.e. final system validation, then there are additional requirements (see Section 2.5.5) that should be considered and reflected in the test plan.

39) Test plans shall indicate how previously identified **HSI** issues and concerns will be evaluated.

40) Test plans shall identify the purpose of the test (e.g., to inform design **Final_System_Validation**).

41) Test plans shall identify the data to be collected by the **Vendor**, including each quantitative measure.

42) Test plans shall identify the following aspects of the methodology: the number of test participants and their demographics, **Use_Case_Scenarios** and how they were selected, test procedures, test instruments, and test equipment.

43) Test plans shall identify the data analysis method(s).

44) Test plans shall identify how the results of the analysis will be used to support the findings of the testing.

45) Test plans shall include the schedule of test plan activities.

2.5.2 Rapid prototypes and user reviews/user evaluations

Designs should be iteratively improved based on testing and feedback from stakeholders and representative users until acceptable solutions are achieved. Representative users are individuals who are represent the target user population in terms of physical attributes, training, experience, knowledge, skills and abilities. Ideally these would-be individuals with direct and recent experience in the position that the system being developed is intended to support (i.e., current target users).

Designers can solicit formal feedback and conduct tests with representative users in multiple ways, including demonstrations, surveys, studies, and experiments. These tests must be accomplished as early as possible and reiterated as the design matures so that their results may be incorporated in the software and hardware design and, if necessary, used to revise earlier HSI decisions, such as function allocation and HSI requirements.

Physical or virtual representations of the design, such as physical mockups, rapid prototypes, and high fidelity simulators, are used to display the evolving design concept. Mockups and rapid prototypes provide ways for stakeholders, including current target users, to have a concrete understanding of the envisioned design so as to provide informed feedback. Rapid prototypes may start as informal paper and pencil sketches, and gradually increase in fidelity ranging from static storyboards, to interactive software prototypes. Eventually high-fidelity physical mockups and dynamic simulators may support both T&E and training activities. The concept of increasing design representation fidelity is illustrated in Figure 6. Early in the design process during analysis activities, the fidelity of any mock-ups/rapid prototyping is very low. As the system moves into the preliminary part of the design stage and then into more detailed design activities, the fidelity increases.

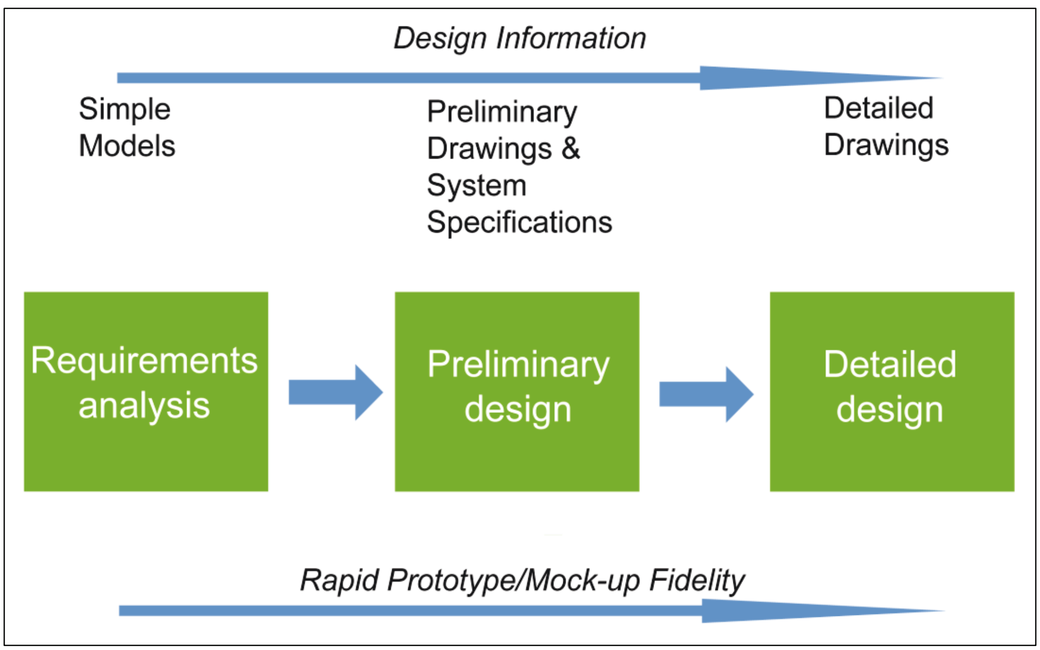

Figure 6. Relationship between the fidelity of mock-ups and the design process. Adapted from figure 4.1 in Hughes, Long, Maddock, and Bearman (2013).

In early iterations, designers may present concepts and solicit input on potential areas of concern and opportunities for improvement. When eliciting user feedback, it is important to solicit input from representative users, preferably current target users who have direct and recent experience in the position that is being supported by the system under development. In addition, feedback should be solicited from multiple individuals with different experiences and levels of expertise (e.g., relatively new hires as well as individuals with many years of experience; train crews that primarily work on the mainline as well as train crews with yard experience).

Soliciting input from multiple individuals with different backgrounds is important to ensure that the feedback does not reflect idiosyncratic personal opinion, but rather reflects an understanding of the requirements of the work and how proposed features of the design may facilitate or complicate work performance. Further, specific user comments should be treated as data to be analyzed for understanding potential design deficiencies and determining how they may be addressed, rather than as literal design guidance to be adopted as stated. For example, if a user suggests making an alert blink so that it is easier to notice, the comment should be taken as an indication that the alert as currently designed does not sufficiently stand out. The design team must come up with a revised proposed way of presenting the alert so that it stands out more clearly; in the end, the team may or may not use blinking as the appropriate design approach for this problem.

In later iterations, representative users may be given hands-on experience with a dynamic, high fidelity prototype, which provides an opportunity to collect objective performance data and identify sources of confusion as well as error-inducing situations. Users may be presented with representative tasks to perform using the high-fidelity prototype. Data can then be collected using multiple objective and subjective measures including task completion time, errors and error recovery, workload, and measures of situation awareness.

46) The **Vendor** shall use **Physical_or_Virtual_Representations** of the system to support **Human-System_Interface** design, including, at minimum, prototypes.

47) The **Vendor** shall use an iterative design approach throughout the **Systems_Engineering** process.

48) The **Vendor** shall identify design improvements by soliciting formal feedback with **Representative_Users** at multiple points in the **Systems_Engineering** effort, starting with concept development through **Final_System_Validation**.

2.5.3 Human Engineering Discrepancy Resolution

The term Human Engineering Discrepancy (HED), as discussed here, refers to any HSI-related deficiency that contributes to human performance problems. This includes aspects of the design, procedures, or training that do not fully support personnel task requirements, contribute to excessive workload or distraction, induce human error or do not support recovery from human error, and create risks to health or safety.

HEDs can be identified at any time during analysis, design, and/or T&E. Indicators of HEDs include instances where performance criteria are not met or where HSI standards and guidelines are violated. Examples of HEDs include human-system interface design incompatibilities, designs that require high physical or mental workload, and designs that require high skill levels resulting in overly costly staffing or training.

Human performance problems that occur during T&E should be analyzed to determine whether they indicate the presence of an HED. Performance problems do not necessarily indicate an HED. For example, if only one of several test participants failed to perform a task satisfactorily and it is determined that the performance difficulty is due to that participant's lack of training, then there may not be evidence of an HED. On the other hand, if multiple test participants exhibit the same performance problem and a feature of the design or training (e.g., a poorly located control; a confusing label) appears to be contributing to the performance problem, then there is evidence of an HED that needs to be corrected. The final system validation report should contain the human performance problems identified during final system validation, indicate whether the problems are evidence of HEDs, and provide justifications for those determinations. (See section 2.5.5 for more on Final System Validation.)

When HEDs are identified, corrective actions should be developed and implemented, such as design, training, or procedural solutions. HED corrective actions do not necessarily require a change in design. They may involve restructuring of tasks or changes in training or procedures to ensure that degraded human performance does not result in degraded system performance.

HEDs should be systematically documented, tracked and resolved. Further guidance on methods for analyzing, tracking, and resolving HEDs can be found in NUREG-0711, Section 11.4.4.

49) The **Vendor** shall document and track **HED**s throughout the entire **Systems_Engineering** process.

50) **HED** tracking shall include a detailed description of the **HED**, its operational impact, the planned **Corrective_Action(s)**, and the status of each **Corrective_Action(s)**.

51) Each **Corrective_Action(s)** taken to address an **HED** associated with a **Critical_Human_Task** shall undergo **Validation**.

2.5.4 Final Verification

One important part of the T&E process is for the vendor to verify the final system to establish that all HSI requirements have been met.

Preparing for final verification should start out early in the design stage of the SE process. While technical HSI requirements are being generated based on the output of analysis activities, vendors should also be developing corresponding statements for how each requirement will be evaluated during the final verification to determine if it has been met. There are several verification techniques that can be used – i.e., inspection, test, analysis, and demonstration -- so for each technical requirement the most appropriate technique must be determined before the verification statement can be written. Table 2 below, adapted from NASA's Human Integration Design Handbook (2010), provides guidance to help determine what type of verification technique is appropriate for the item being tested. Additional guidance and specific examples of each type of verification technique can be found in NASA (2010) and INCOSE (2015).

Table 2. Verification Techniques (adapted from NASA, 2010)

Verification Technique	**Technique Selection Criteria**	**Example Application**
Inspection	**When to Use:** If a person can observe or use a simple measurement to determine whether the requirement is satisfied, inspection is the proper method. The risk with this method is inherent in the fact that an inspector makes the measurement or judgment. Inspection is typically the least expensive verification method. **Attributes for verification:** What is to be inspected, How is it to be inspected, Who will inspect it, What is the success criterion?	Confirming use of a particular font or character size on a display by direct observation or measurement.

Test	**When to Use:** If an experiment and subsequent data analysis are needed for verification, testing is the proper method. A test-based verification should provide a thorough description of the experiment. The success criteria for a test may be best stated probabilistically. Testing is typically the best and most effective method to quantify and reduce risk. Testing can be expensive. Attributes for verification: the measure, initial conditions, assumptions, experiment description, hardware and software to be used, success criterion.	Confirming that the population of users can perform an action (e.g., initiate an emergency brake) within a specified time limit by having multiple individuals representative of the target user population perform the action under a range of realistic conditions.
Analysis	**When to Use:** If verification can be accomplished by evaluation of equations, analysis is the proper method. The risk with analysis is inherent in the assumptions and model fidelity. Analysis is generally much less expensive than Test. **Attributes for verification:** the measure, initial conditions, assumptions, sources of equations, details of simulation, hardware and software to be used, success criterion.	Confirming that the time required to complete a multistep task (e.g., navigating through multiple menus to initiate a system) is less than a criterion value by using a cognitive simulation model to estimate the time it will take to complete the task.

Demonstration	**When to Use:** If verification can be accomplished with an experiment on actual system hardware or software, and only a single datum or result is needed (no data analysis, a simple pass/fail), then demonstration is the proper method. A demonstration is usually performed at the extremes in range of performance (i.e., worst-case environment or scenarios). The risk with demonstration is that there is only one datum on which the pass/fail decision is made. **Attributes for verification:** the measure or function, initial conditions, assumptions, specific instructions, hardware and software to be used, success criterion.	Confirming that a procedure correctly specifies the set of steps required to complete a task by having a single individual perform the steps in the procedure to establish that the procedure is correct.

> 52) The **Vendor** shall perform a **Final_ Verification** to confirm that all **HSI** requirements have been met.

2.5.5 Final System Validation

A final system validation should be performed as part of acceptance testing prior to full implementation. The objective of the final system validation is to collect objective evidence that the final system design is able to accomplish its intended use, goals, and objectives in the intended operational environment and that it supports safe operation. The final system validation includes human-in-the-loop testing performed using the final integrated system to be fielded. It should be conducted in the actual operational environment or in a dynamic, high fidelity simulator.

In a final system validation, representative users are run through a set of evaluation scenarios (NASA/SP- 2010-3407, 2014; NUREG-CR-0711). The evaluation scenarios should include the operational contexts and use case scenarios defined during analysis activities (see Section 2.3.2). Particular emphasis should be placed on evaluating performance on critical human tasks under challenging operational contexts.

This is a final check on the system to ensure that requirements are met and that there are no outstanding HEDs that have not yet been addressed. A variety of objective data should be collected including:

- Individual and team process measures (e.g., measures of workload, measures of situation awareness, measures of focus of attention such as eye-movement data; measures of teamwork);
- Outcome measures (e.g., whether task performance on critical human tasks met success criteria; whether there were any errors or suboptimal performance on critical human tasks such as exceeding limits of authority; or triggering a penalty brake);
- User assessments in the form of closed-form rating questions and open-ended questions soliciting feedback.
- Workload and situation awareness are two critical process measures that should be collected. Section 2.3.4 includes discussion of these concepts and ways to measure them.

Any performance problems or negative user assessments should be subjected to an HED analysis (see Section 2.5.3) to determine whether there are any changes needed to the system.

Any corrective action that results from HED analysis should be subjected to further validation to establish that the human performance problem has been eliminated and no new HEDs have emerged. Due to prior T&E activities that should have taken place throughout the design process (e.g., see Section 2.5.2) there should not be any major surprises at this stage.

53) In addition to individual tests and evaluations that may occur at various stages in system, subsystem, equipment, or facility development, the Vendor shall perform a **Final_System_Validation** on the **Final_Integrated_System_Design**.

54) The **Final_System_Validation** shall include **Human-in-the-Loop_Test(s)** performed in a dynamic high-fidelity simulator or the actual operational environment.

55) During the **Final_System_Validation**, the **Vendor** shall evaluate performance on **Critical_Human_Tasks** under challenging operational conditions.

56) **Final_System_Validation** shall include performance of operator tasks for **Normal_Modes**, **Emergency_ Modes**, and **Degraded_Modes**.

57) **Final_System_Validation** shall include performance of maintainer tasks for **Normal_Modes**, **Emergency_Modes**, and **Degraded_Modes**.

58) **Final_System_Validation** shall include performance of support staff tasks for **Normal_Modes**, **Emergency_Modes**, and **Degraded_Modes**.

59) The **Final_System_Validation** test participants shall be **Representative_Users**.

60) During **Final_System_Validation**, the Vendor shall examine each **Human_Performance** problem to determine if **HED**s are present.

61) The **Vendor** shall identify **Corrective_Action(s)** for **HED**s occurring during **Final_System_Validation** that impact **Critical_Human_Tasks**.

62) The **Vendor** shall document and provide the results of the **Final_System_Validation** to the **Procuring_Organization**.

63) **Final_System_Validation** shall include an assessment of **Workload**.

64) **Final_System_Validation** shall include an assessment of **Situation_Awareness**.

2.5.6 Evaluation Staff

In T&E activities, it's essential that HSI practitioners help oversee the testing process of HSI-related items and interpret the results. HSI practitioners should take the lead in developing the HSI test plan(s). They should also have lead responsibility for conducting evaluations and analyzing the results. As Folds (2015) points out, there can be hundreds of pass-fail outcomes on a final system test and it requires a knowledgeable HSI practitioner to determine the significance of the results, and discern which things are trivial (e.g. things that would be good to correct, but not absolutely needed and might not be worth it) versus which things are moderately serious and must be carefully considered.

In order to avoid bias, the staff responsible for validation activities should be different than the staff responsible for system design.

65) **HSI_Practitioner(s)** shall oversee and participate in the **Test_and_Evaluation** of **HSI**-related items.

66) **HSI_Practitioner(s)** shall oversee and participate in the interpretation of **HSI**-related **Test_and_Evaluation** results.

3. Conclusion

This report recommends that the railroad industry adopt an HSI approach to the development of new railroad systems technologies, such as next generation locomotive cabs. Adopting an HSI approach will ensure that new systems foster safe and efficient performance, and reduce total life cycle costs.

This document describes how railroads can incorporate HSI into their acquisition processes for procuring new systems from vendors—specifically, by including a listing of HSI requirements that railroads can direct their vendors to meet. The requirements are discussed in Section 2, and provided as an itemized list in Appendix A; a glossary of requirement terms is included in Appendix B. Appendix G provides additional resources for more in-depth descriptions of the concepts, methods, and requirements rationale introduced in Section 2.

The report also recommends that vendors be required to submit an HSIPP, which details among other things, the vendor's HSI-related qualifications, organizational structure, activity plan and associated schedule. Railroads should request vendors to include the HSIPP as part of their proposal submittal package. This requirement signals to vendors that HSI is important to the railroad and encourages them to prepare a well-thought-out plan. It would also facilitate the railroad's proposal evaluation process by enabling comparison across vendors based upon the quality of their proposed HSIPPs. Appendix E offers a recommended template for an HSIPP that railroads can tailor to their specific technology procurement needs.

3.1 The Way Forward

The recommended next steps to railroads would be to begin by implementing requirements that can most easily be accommodated within their existing engineering processes and continue making progress toward the remaining requirements.[14] The anticipated benefits include reduced design costs due to decreased need for rework, reduced total lifecycle costs, and improved operational safety and efficiency.

One of the most important steps to move forward is for railroads to acquire in-house or contracted HSI expertise of their own. At least one representative (preferably more than one) from the railroad with HSI expertise should be involved throughout the acquisition and SE process. In addition, those at the higher levels of program and organizational management should familiarize themselves with the fundamentals of HSI and why it is critical for good design outcomes, and provide basic HSI training opportunities for their staff, particularly those involved with acquisitions. As a useful starting point for those seeking formal HSI training, Appendix F lists several resources for highly regarded HSI courses and programs.

[14] Chapter 8 of INCOSE (2015) discusses considerations and techniques for tailoring system engineering processes to particular application domains. These can be drawn upon to tailor HSI processes for railroad application.

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Appendix A.
Summary List of Requirements

The requirements that appear throughout the document are listed below. For more information regarding any particular requirement, please see the body of the report. In particular, procuring organizations may want to direct their vendors to our report for more information. There are topics that the report discusses but have no recommended requirements (e.g. HSI Practitioner Qualifications; use of Integrated Product Teams). In those cases, this document provides some general guidance for the procuring railroad or addresses the issue through the requirements outlined in the HSI Program Plan (HSIPP) (see Appendix E for HSIPP template).

Please note that this list draws extensively from FAA STD HF-STD-004 (FAA, 2009) and many requirements in the current work are borrowed or adapted from that document.

PROGRAM MANAGEMENT AND CONTROL:

Human Systems Integration Program Plan

1) The **Vendor** shall describe **HSI** activities in the **HSIPP**.

2) The **Vendor** shall prepare the **HSIPP** in accordance with the template provided by the **Procuring_Organization**.

3) The **Vendor** shall update the **HSIPP** at every milestone.

Integrating HSI Practitioners into the Systems Engineering Process

4) The **Vendor** shall integrate the **HSI** program into the total **Systems_Engineering** process.

5) **HSI_Practitioner(s)** shall participate in program, technical, design, and system reviews.

6) **HSI_Practitioner(s)** shall, at minimum, review, edit, and approve **HSI** requirements.

7) The **Responsible_HSI_Practitioner** shall have sign off authority for each portion of the program's analysis, design and development, and **T&E** that involves a **Human-System_Interface** or impacts **Human_Performance**.

8) The **HSI** program shall be executed by **HSI_Practitioner(s)**.

Program Risk Management

9) The **Vendor** shall demonstrate consideration of **User** capabilities and limitations in **Concept_of_Operations** and **Functional_Requirements** documents.

10) **Program_Risk_Management** shall identify potential cost, schedule, design, and performance risks that result from **HSI** design issues.

11) **Program_Risk_Management** shall analyze, prioritize and take actions to avoid, minimize, control, or accept each **HSI** risk.

12) **Program_Risk_Management** shall document and track each identified **HSI** risk, the impact of those risks, and the mitigation actions taken.

13) **Program_Risk_Management** shall include each **HSI** risk in the program's risk management process.

Traceability

14) **Vendor** documentation shall provide traceability from initial identification of **HSI** requirements through **Final_Verification** that these requirements have been met.

Operational Experts

15) **Operational_Experts**, including current target **User(s)**, shall actively participate in analysis, design and development, and **T&E** activities.

ANALYSIS:

Concept of Operation

16) The **Vendor** shall specify a **Concept_of_Operations** that describes the characteristics of the proposed system from the viewpoint of the **User(s)**.

Operational Contexts and Use Case Scenarios

17) The **Vendor** shall provide a range of **Use_Case_Scenarios** that include routine operational contexts as well as challenging operational contexts as input to design requirements, design demonstration, and **T&E**.

18) The **Vendor** shall identify **Critical_Human_Tasks** for operational, maintenance, and support activities.

19) **Use_Case_Scenarios** shall include **Critical_Human_Tasks** and operational contexts that

challenge **User(s)**.

Lessons Learned Review

20) The **Vendor** shall conduct a **Lessons_Learned_Review**.

21) The **Lessons_Learned_Review** shall include a review of operating experience with predecessor systems.

22) The **Lessons_Learned_Review** shall include a review of similar systems in other domains.

23) The **Lessons_Learned_Review** shall identify **Human_Performance** issues and design challenges requiring special attention in design, evaluation, and **Final_System_Validation** of the system.

Assignment and Detailed Understanding of Tasks

24) The **Vendor** shall use **HSI_Methods** to analyze the functions assigned to humans within the system.

25) The **Vendor** shall use **HSI_Methods** to identify the cognitive and physical tasks, including requirements for maintaining **Situation_Awareness**, and **Workload** associated with the functions assigned to humans within the system.

26) The **Vendor** shall analyze **Critical_Human_Tasks** to identify conditions that can adversely affect the ability of the **User(s)** to accomplish the task in accordance with system requirements.

Safety Risk Analysis and Management

27) The **Safety_Risk_Management** process shall include **HSI** risks.

28) The **Vendor** shall use a systematic approach to analyze, evaluate, and mitigate **Human_Performance**-related risks that can impact the overall safety of the system.

Tradeoff Analyses

29) The **Vendor** shall consider and address tradeoffs among **HSI_Domains**.

30) The **Vendor** shall consider and address tradeoffs between **HSI** and other software and hardware factors.

31) Tradeoff analyses shall consider the **Human_Performance** impact on total system performance and life cycle cost.

DESIGN AND DEVELOPMENT:

Work Environment Design

32) The **Vendor** shall apply **HSI_Methods** to detailed design of **User(s)'** physical work environments.

Human Computer Interface/Software Design

33) The **Vendor** shall apply **HSI_Methods** to the design of software systems that require **User(s)** interaction.

34) The **Vendor** shall apply **HSI_Methods** to the design of hardware that require **User(s)** interaction.

Design of Procedures, Manuals, and Documentation

35) The **Vendor** shall apply **HSI_Methods** to the development of all electronic and hard-copy documentation.

36) The **Vendor** shall apply **HSI_Methods** to the development of all electronic and hard-copy training materials.

Participation in Design and Review of Systems and Subsystems

37) **HSI_Practitioner(s)** shall participate in design reviews and engineering change proposal reviews of each system component that involves a **Human-System Interface**.

TEST AND EVALUATION (T&E):

T&E Planning

38) The **Vendor** shall incorporate **HSI** testing into the system **T&E** program.

39) Test plans shall indicate how previously identified **HSI** issues and concerns will be evaluated.

40) Test plans shall identify the purpose of the test (e.g., to inform design, **Final_System_Validation**).

41) Test plans shall identify the data to be collected by the **Vendor**, including each quantitative measure.

42) Test plans shall identify the following aspects of the methodology: the number of test participants and their demographics, **Use_Case_Scenarios** and how they were selected, test procedures, test instruments, and test equipment.

43) Test plans shall identify the data analysis method(s).

44) Test plans shall identify how the results of the analysis will be used to support the findings of the testing.

45) Test plans shall include the schedule of test plan activities.

Rapid prototypes and user reviews/user evaluations

46) The **Vendor** shall use **Physical_or_Virtual_Representations** of the system to support **Human-System_Interface** design, including, at minimum, prototypes.

47) The **Vendor** shall use an iterative design approach throughout the **Systems_Engineering** process.

48) The **Vendor** shall identify design improvements by soliciting formal feedback with **Representative_Users** at multiple points in the **Systems_Engineering** effort, starting with concept development through **Final_System_Validation**.

Human Engineering Discrepancy Resolution

49) The **Vendor** shall document and track **HED**s throughout the entire **Systems_Engineering** process.

50) **HED** tracking shall include a detailed description of the **HED**, its operational impact, the planned **Corrective_Action(s)**, and the status of each **Corrective_Action(s)**.

51) Each **Corrective_Action(s)** taken to address an **HED** associated with a **Critical_Human_Task** shall undergo **Validation**.

Final Verification

52) The **Vendor** shall perform a **Final_ Verification** to confirm that all **HSI** requirements have been met.

Final System Validation

53) In addition to individual tests and evaluations that may occur at various stages in system, subsystem, equipment, or facility development, the **Vendor** shall perform a **Final_System_Validation** on the **Final_Integrated_System_Design**.

54) The **Final_System_Validation** shall include **Human-in-the-Loop_Test(s)** performed in a dynamic high-fidelity simulator or the actual operational environment.

55) During the **Final_System_Validation**, the **Vendor** shall evaluate performance on **Critical_Human_Tasks** under challenging operational conditions.

56) **Final_System_Validation** shall include performance of operator tasks for **Normal_Modes**, **Emergency_Modes**, and **Degraded_Modes**.

57) **Final_System_Validation** shall include performance of maintainer tasks for **Normal_Modes**, **Emergency_ Modes**, and **Degraded_Modes**.

58) **Final_System_Validation** shall include performance of support staff tasks for **Normal_Modes**, **Emergency_Modes**, and **Degraded_Modes**.

59) The **Final_System_Validation** test participants shall be **Representative_Users**.

60) During **Final_System_Validation**, the **Vendor** shall examine each **Human_Performance** problem to determine if **HED**s are present.

61) The **Vendor** shall identify **Corrective_Action(s)** for **HED**s occurring during **Final_System_Validation** that impact **Critical_Human_Tasks**.

62) The **Vendor** shall document and provide the results of the **Final_System_Validation** to the **Procuring_Organization.**

63) **Final_System_Validation** shall include an assessment of **Workload**.

64) **Final_System_Validation** shall include an assessment of **Situation_Awareness**.

Evaluation Staff

65) **HSI_Practitioner(s)** shall oversee and participate in the **Test_and_Evaluation** of **HSI**-related

items.

66) **HSI_Practitioner(s)** shall oversee and participate in the interpretation of **HSI**-related **Test_and_Evaluation** results.

Appendix B.
Glossary of Terms Used in Requirements

This is a glossary of terms used in the HSI acquisition requirements laid out by this report (see Appendix A). It is intended to accompany the list of requirements in the procuring organization's RFP. However, it may also be of use to those reading the report. Glossary terms are easily identified when reading requirements, whether in Appendix A or in the grey boxes in the body of this report, because they are in bolded text.

Some of these glossary definitions are borrowed or adapted from other sources as denoted by the symbol in parentheses. The sources used are at the bottom of this appendix.

Glossary Term	Definition
Concept of Operations	High-level description of the envisioned objectives, roles and responsibilities of the user(s) in the new (or redesigned) system.
Corrective Action(s)	Changes in design, restructuring of tasks, or changes in training or procedures used to rectify HEDs.
Critical Human Tasks	A task requiring human performance which, if not accomplished in accordance with system requirements, will likely have adverse effects on cost, system reliability, efficiency, effectiveness, or safety. A task is also considered critical whenever equipment design characteristics demand human performance which approaches the limits of human capabilities. (*)
Degraded Modes	Mode where certain elements are not working or only partially working. E.g. if an automated system cuts out.
Emergency Modes	Emergency situations that require actions to be taken to avoid or mitigate damage to equipment or harm to people.
Final Integrated System Design	A running implementation of final system design that includes all hardware, software, and personnel elements. (***)
Final System Validation	Performance tests of the final integrated system design that includes Human-In-The-Loop Test(s) conducted in the actual operational environment or a dynamic, high fidelity simulator. The objective of the final system validation is to determine whether the final system design meets performance requirements and supports safe operation. (***)
Final Verification	A process that is conducted on the final design to establish that all requirements have been met. (**)
Functional Requirements	Requirements that define the behaviors or functions of the system without describing the specific details of implementation.

Human Engineering Discrepancy (HED)	Any HSI-related deficiency that contributes to human performance problems. This includes aspects of the design, procedures, or training that do not fully support personnel task requirements; that contribute to excessive workload or distraction; that induce human error or do not support recovery from human error; and/or that create risks to health or safety.
Human Systems Integration (HSI)	A systematic process that integrates human performance considerations into the design and acquisition of complex systems.
HSI Domains	HSI domains include: Manpower, Personnel, Training, Human Factors Engineering, Safety, Occupational Health, Environment, Habitability and Survivability.
HSI Methods	Established methods developed and used by the HSI Practitioners that are covered in HSI courses and books.
HSI Practitioner(s)	Someone who is qualified with relevant training and experience in one or more HSI domains.
Human Systems Integration Program Plan (HSIPP)	Document created prior to the start of the SE process that details the HSI work that will be performed, how it will be done, and by whom. This typically should be done as part of the vendor's proposal submittal package.
Human-in-the-Loop Test(s)	Representative users are run through a set of evaluation scenarios in the actual work environment or a high-fidelity simulator to as part of final system validation.
Human-System Interface	That part of the system through which users (including operations, maintenance, and support staff) interact to perform their functions and tasks. These include information displays, controls, alerts, and job aids. (***)
Human Performance	A measure of human functions and actions in a specified environment, reflecting the ability of actual operators and maintainers to meet the system's performance standards, under the conditions in which the system, equipment, or facility will be employed. (*)
Lessons Learned Review	Review of prior experience with predecessor systems and similar systems implemented in related domains to identify human performance concerns and design challenges that will require special attention in design and evaluation. Output of this review is a set of human performance issues, as well as potential design solutions, to guide the system design and evaluation process.

Normal Modes	The range of routine conditions under which the system equipment will be employed.
Operational Experts	Individuals with direct knowledge and experience relating to the operational context in which the system will be used. These are sometimes referred to as subject matter experts (SMEs).
Physical and Virtual Representations	Any physical or software model of the system, such as story boards, physical mockups, models, prototypes, or simulations.
Procuring Organization	The customer who is purchasing new equipment, systems, or facilities from a vendor.
Program Risk Management	Identifying and managing risks associated with technical, cost, or schedule issues that can jeopardize the success or schedule of a system development project, including risks associated with design of components that involve extensive human interaction.
Representative users	Individuals representative of the User(s) population with respect to the range of physical attributes, training, experience, knowledge, skills and abilities.
Responsible HSI Practitioner	The HSI Practitioner(s) with primary responsibility for HSI work and outcomes in a given area (as defined by the HSIPP) and who has sign off authority in that same area.
Safety Risk Management	Identifying and managing risks, including human performance related risks that can impact the overall safety of a system once it is operational.
Situation Awareness	Awareness of the elements of the immediate environment, comprehension of implications, and anticipation of what is coming in the future.
Systems Engineering (SE)	Systems engineering is an interdisciplinary field of engineering that employs a systematic process to the design of complex systems. The systems engineering process encompasses defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost, and schedule, performance, training and support, test, manufacturing, and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. (**)
Test and Evaluation (T&E)	T&E activities establish that the system requirements as specified have been met (referred to as verification activities) and that the final designed system meets high level system goals such operating safely,

	efficiently, and effectively (referred to as validation activities). T&E activities happen throughout system development. Initial evaluations may take the form of informal reviews with users and stakeholders. As the design matures and rapid computer-based prototypes become available, HSI practitioners can conduct more formal user tests where qualitative observations, quantitative performance data, and user feedback can identify design deficiencies that need to be addressed in later design cycles. T&E concludes with a final system validation in a high fidelity simulator or the actual operational environment.
Use Case Scenarios	Use case scenarios provide concrete illustration of the range of operational conditions and complexities that the system needs to be able to handle. Typically, use case scenarios identify actors, contextual situation, information requirements, decisions (induction/deduction), time constraints (available/required), etc.
User(s)	Those individuals which utilize the system in their work, including system operators, maintainers, and support staff.
Validation	A set of test activities performed to collect objective evidence that a system is able to accomplish its intended use, goals, and objectives in the intended operational environment. *(** ; See also Final System Validation.)*
Vendor	An organization hired to engineer and build equipment, systems, or facilities for the Procuring Organization under the terms specified in a contract.
Verification	*(See Final Verification.)*
Workload	The physical and mental (cognitive) demands that tasks place on users of a system. (***)

Glossary References:

* Federal Aviation Administration (2009). Requirements for a Human Factors Program (HF-STD- 004). Washington, D.C.

** INCOSE. (2015). Systems Engineering Handbook: A guide for System Life Cycle Processes and Activities (Vol. 4.0). Hoboken, NJ: John Wiley and Sons.

*** NUREG-0711 (2012). Human Factors Engineering Program Review Model. Washington, DC: U. S Nuclear Regulatory Commission. (NUREG-0711, rev3).

Appendix C.
Verification Criteria

This is a list of verification criteria that can be used to determine whether HSI process requirements specified in this report have been met by the vendor. These verification criteria can be established by direct inspection.

Number	Verification Criteria For Each Requirement
1	Is there a HSIPP that describes HSI activities?
2	Is the HSIPP prepared in accordance with the template provided by the Procuring Organization?
3	Is Vendor updating the HSIPP at every milestone?
4	Does the organizational structure, as reflected in program organization and workflow documents, provide evidence (e.g., organizational charts, cross-organization workflow charts) that HSI activities are being integrated within the larger systems engineering process?
5	Do the program organization and workflow documents provide evidence that HSI Practitioner(s) will participate in program, technical, design and system reviews (e.g., organizational charts, cross-organization workflow and responsibility charts)?
6	Do the program organization and workflow documents provide evidence that HSI requirements will be at a minimum reviewed, edited and approved by an HSI practitioner?
7	Do the program organization and workflow documents provide evidence that an HSI practitioner will have sign off authority for those portions of the program's analysis, design and development, and T&E that involve a human-system interface or otherwise impact human performance? Do the program organization and workflow documents specify the portions of the program's analysis, design and development, and T&E that involve a human-system interface or otherwise impact human-system performance?
8	Do the background and credentials of the individuals executing the HSI program indicate that they have the relevant training, experience, and qualifications for the HSI program responsibilities they have been assigned?
9	Do the concept of operations and functional requirements documents include information providing evidence that user capabilities and limitations are being considered?

10	Is there a process in place to identify potential cost, schedule, design, and performance risks that result from HSI design issues?
11	Is there a process to analyze, prioritize and take action to minimize, control or accept each HSI risk?
12	Is there a system in place to document and track each HSI risk, the impact of those risks, and the mitigation actions taken?
13	Is each HSI risk integrated into the larger program risk management system and processes?
14	Is there a system in place to document and track HSI requirements from initial identification of HSI requirements through Final_Verification and whether each requirement has been met?
15	Is there a process in place for operational experts, including current target users to participate in analysis, design and T&E activities?
16	Is there a documented description of a concept of operations that specifies characteristics of the proposed system from the viewpoint of the User(s)?
17	Has a set of use case scenarios been defined that span the range of routine operational contexts as well as challenging operational contexts? Have these use case scenarios been used as input to design requirements, design demonstration, and T&E?
18	Has a set of critical human tasks been identified for operational, maintenance, and support activities?
19	Does the set of use case scenarios include critical human tasks and operational contexts that challenge users?
20	Has a lessons learned review been conducted?
21	Does the lesson learned review cover operating experience with predecessor systems?
22	Does the lessons learned review include review of operational experience with similar systems in related domains?
23	Does the lessons learned review identify human performance issues and design challenges requiring special attention in design, evaluation, and final system validation of the system?
24	Have HSI methods been applied to analyze the functions assigned to humans within the system?
25	Have HSI methods been applied to identify the cognitive and physical tasks (including requirements for maintaining situation awareness) and the workload associated with the functions assigned to humans within the system?

26	Have critical human tasks been analyzed to identify conditions that can adversely affect the ability of the User(s) to accomplish the task in accordance with system requirements?
27	Are HSI risks included in the larger system safety risk management process?
28	Has the vendor analyzed and evaluated human performance related risks? Have mitigation strategies been identified and implemented to reduce human performance related risks?
29	Is there documented evidence that tradeoffs between HSI domains have been considered?
30	Is there documented evidence that tradeoffs between HSI and other software and hardware factors have been considered?
31	When tradeoff analyses have been conducted, has the impact of human performance on total system performance been analyzed and documented? When tradeoff analyses have been conducted, has the impact of human performance on total life cycle cost been analyzed and documented?
32	Have HSI design methods been applied to detailed design of physical work environments?
33	Have HSI design methods been applied to the design of software systems that require user interaction?
34	Have HSI design methods been applied to the design of hardware that requires user interaction?
35	Have HSI methods been applied to development of all electronic and hard-copy documentation?
36	Have HSI methods been applied to development of all electronic and hard-copy training materials?
37	Do HSI practitioners participate in design reviews and engineering change proposal reviews of each system component that involves a human-system interface?
38	Is HSI testing included in the system T&E program?
39	Have test plans been produced? Do the test plans specify HSI issues and concerns that have been identified by earlier design and test activities? Do the test plans indicate how those HSI issues and concerns will be evaluated?
40	Do test plans identify the purpose of the test (e.g., to inform design, final system validation)?
41	Do test plans identify the data to be collected, including each quantitative measure?

42	Do test plans identify each of the following aspects of the methodology: the number of test participants and their demographics, Use_Case_Scenarios and how they were selected, test procedures, test instruments, and test equipment?
43	Do test plans identify the method(s) by which the data will be analyzed?
44	Do test plans identify how the results of the analysis will be used to support the overall findings of the testing?
45	Do test plans include the schedule of test plan activities?
46	Have physical or virtual representations of the system been used to support human-system interface design?
47	Has an iterative design approach been used throughout the system engineering process?
48	Has formal feedback from representative users been obtained at multiple points in the system engineering effort? Have the results been used to make design improvements?
49	Is there a database for documenting and tracking HEDs? Has it been used throughout the entire systems engineering process?
50	Does the HED tracking system contain the following elements: a detailed description of the HED, its operational impact, planned corrective action, and status of each corrective action? Is the HED tracking system being used to track HEDs, corrective actions, and their status? Have corrective actions been identified and implemented for all HEDs?
51	Has each corrective action taken to address an HED associated with a critical human task been subject to validation?
52	Has a final verification been performed?
53	Has a final system validation been performed on the final integrated system design?
54	Did the final system validation include human-in-the-loop tests performed in either a high fidelity simulator or the actual operational environment?
55	Did the final system validation include a test of performance on critical human tasks under challenging operational conditions?
56	Did the final system validation include operator tasks for normal modes, emergency modes, and degraded modes?
57	Did the final system validation include maintenance tasks for normal modes, emergency modes, and degraded modes?

58	Did the final system validation include support staff tasks for normal modes, emergency modes, and degraded modes?
59	Are test participants representative users?
60	Has an HSI review been conducted to determine whether human performance problems that arose during the final system validation indicate the presence of an HED?
61	Have corrective actions been identified for HEDs occurring during the final system validation that impact critical human tasks?
62	Have results of the final system validation been documented and provided to the procuring organization?
63	Did the final system validation include assessment of workload?
64	Did the final system validation include assessment of situation awareness?
65	Have HSI Practitioner(s) overseen and participated in the testing and evaluation of HSI- related items?
66	Have HSI Practitioner(s) overseen and participated in the interpretation of HSI-related T&E results?

Appendix D.
Summary List of HSI Data Items

This is a summary list of HSI-related data items. The term “data item” refers to a document, database or other file type deemed appropriate to addresses these requirements. Content from data items listed below may be combined in to a single data item where appropriate.

The list reflects the items that vendors shall produce along with some additional items (denoted by an asterisk) which should not be required across all systems acquisitions, but which a procuring railroad may choose to require. For example, HSI staff on the railroad side can make good use of task analysis information to design or make improvements to training programs and procedures. The items without an asterisk are required by the “shall statements” throughout the report and listed in Appendix A. More information on each of these data item requirements can be found in the section referenced in the table.

Data Item	Time Frame	Section
HSI Program Plan	Prior to award of contract	2.2.1; Appendix E
Lessons Learned Review	During analysis activities	2.3.3
Report summarizing results of any function allocation and task analyses activities *	After conclusion of these activities or at conclusion of project.	2.3.4
Documentation of Risks	During analysis activities	2.3.5
Database or other data item tracking HEDs and how they are addressed	Maintained throughout entire systems engineering process. Available for review, as needed, and at major program milestone reviews.	2.5.3
Final System Validation Report	After validation of the final system	2.5.5

Appendix E.
HSI Program Plan (HSIPP) Template

This template contains the format and content preparation instructions for the Human Systems Integration Program Plan (HSIPP) resulting from applicable tasks delineated in the contract Statement of Work (SOW

PREPARATION INSTRUCTIONS

1. **Reference documents**. The applicable issue of the documents cited herein, including their approval dates and dates of any applicable amendments, notices, and revisions shall be as specified in the contract.
2. **Content**. The Human Systems Integration Program Plan (HSIPP) shall contain the following sections, as described:

    a) Front Matter. Table of contents; list of tables, figures, and appendices, as applicable; and a list of acronyms and abbreviations.

    b) Overview. Briefly describe the following:

    1) HSIPP purpose and scope,
    2) An overview of the system being proposed, a preliminary concept of operation for the envisioned system, associated human role(s) (i.e., functions assigned to humans), and operational environment,
    3) Experiences with predecessor systems and related technologies from which lessons learned will be derived,
    4) Human Systems Integration (HSI) objectives for the program,
    5) The HSI domains that will be addressed, and the strategy for addressing HSI domain objectives individually and in any domain tradeoff analyses.

    c) Program Management and Control

    1) **Organization.**

        i. Identify, describe, and provide an organization chart of the vendor's primary organizational element(s) and primary HSI organizational element(s).

        ii. Identify the HSI domain(s) addressed by each element; to whom the HSI manager/lead and HSI domain leads report; and the reporting and responsibility relationships between the HSI manager/lead and HSI domain leads.

        iii. For key positions (e.g., HSI manager/lead, domain leads, key HSI practitioners), provide summary job descriptions (i.e. roles and responsibilities) and the qualifications of these staff.

iv. Designate the individual(s) with sign off authority in each HSI work area. This should be the HSI Practitioner(s) with primary responsibility for HSI work and outcomes in that area.

v. If an HSI Integrated Product Team (IPT) will be used, describe the composition of the HSI IPT (e.g., contractor, subcontractor, and procuring railroad HSI domain representatives and user group representatives), and its responsibility, authority, and accountability for ensuring compliance with HSI requirements.

2) **Organizational relationships.** Describe the relationships of the vendor's HSI organization element(s) to other vendor organization elements responsible for areas impacted by HSI, such as systems engineering; hardware and software design teams; safety, training; test and evaluation (T&E); and related disciplines (e.g. reliability, maintainability).

3) **Subcontractor/subvendor efforts.** If subcontractors are responsible for work on hardware or software components that have user (operator, maintainer, or support staff) interfaces, or subcontractors conduct other HSI efforts (e.g. serving as a subject matter experts, performing trade studies) the following shall be included. Describe the subcontractor's organizational element responsible for HSI and the subcontractor's HSI activities. Describe the method(s) by which the prime contractor will monitor subcontract compliance with HSI requirements.

4) **HSI relationship to Procuring Organization.** Detail the procuring organization's responsibilities with regard to HSI. Identify any data, software, databases, models, access to operational experts and representative users, or equipment required from the procuring agency to accomplish the described HSI activities.

5) **Program Risks:** Specify how HSI-related risks (e.g. those arising from human performance issues and human factors design issues) that may contribute to technical, cost or schedule issues will be identified and addressed.

6) **Time-Phase schedule and level of effort.** Provide a milestone chart that identifies each separate HSI activity to be accomplished during the contract period of performance. Include key HSI decision points and their relationship to the program milestones. Provide information on the proposed number of HSI personnel on an annual basis.

7) **HSI Program Quality Control.** Describe the approach for periodically assessing the quality (relative success and progress) of the overall HSI effort and each HSI domain over the course of the contract.

d) **Data Sources.** Identify vendor, industry, technical society and government standards, handbooks, and other documents that will be applied to the HSI effort and activities and any proposed tailoring. Also identify primary customer requirements documents and contract documents that impact the vendor's HSI effort and activities.

e) **Analysis**

1) Describe the HSI activities that will be conducted to specify human-related system requirements, and the organizational element(s) responsible for their conduct.

2) Include a description of the process that will be used to specify each of the following:

   i. The concept of operation

   ii. Operational contexts and use case scenarios

   iii. Human performance issues and design challenges as derived from lessons learned review

   iv. User functions and tasks

   v. Human performance contributors to risk and safety

f) Design & Development

1) Describe the HSI activities that will be conducted to design and develop the hardware and software elements with which operations, maintenance, and support personnel will interact. Specify the organizational element(s) responsible for the conduct of these activities.

2) Include a description of the process that will be used to specify:

   i. Work environment design

   ii. Human computer interface/software design

   iii. Design of procedures, manuals and documentation, including training materials

3) Describe the process that will be used to ensure that hardware and software designs meet the established standards and guidelines specified by the Vendor in Section 2d, *Data Sources*.

4) Describe HSI participation in the preparation of system design and performance specifications; selection of commercial off-the-shelf or non-developmental items; tradeoff analyses; and system and program technical reviews.

5) Describe the planned involvement of (and coordination to obtain) current target users (e.g. locomotive engineers, conductors, maintenance crew) in assessing the design, operation, maintenance, training, and support of the system.

g) T&E

1) Describe HSI participation in T&E activities as part of the vendor's integrated T&E program. Describe how (e.g., methods, metrics, and tools) and when the vendor will test, evaluate and validate requirements related to HSI. Specify the organizational element(s) responsible for the conduct of these activities.

2) Include a description of the process that will be used to:

i. Conduct user reviews and evaluations of rapid prototypes

ii. Identify and resolve human engineering discrepancies (HED)s

iii. Conduct human-in-the-loop evaluation as part of final system validation

3) Identify design milestones at which HSI tests are to be performed to assess compatibility among human performance requirements, staffing requirements, personnel aptitude and skill requirements, training requirements, and equipment design aspects of personnel hardware and software interfaces. Provide a summary schedule that depicts HSI tests, evaluations, and verification activities in support of program milestones.

h) Operational Experts and Users. Describe what operational experts and current target users will be participating and what role they will play in HSI analysis, design and development, and T&E activities. Specify the level of involvement (i.e., anticipated person hours), how they will be recruited, and how they will be compensated for their time to ensure their availability to the program.

i) Support of affordability and performance goals. Describe the methods by which the vendor will identify and conduct tradeoffs of risks and issues among HSI domains, and between HSI and other program disciplines in support of primary HSI goals: to reduce total system ownership costs; improve total system performance; and ensure that the system accommodates the characteristics of the user population that will operate, maintain, train, support, and, if applicable, manufacture it. Describe how the vendor will ensure that HSI cost and performance factors will be formally considered during analysis, and design and development; during technical reviews (e.g. System Requirements Review, Systems Functional Review, Preliminary Design Review, Critical Design Review); and in the engineering change management process.

j) Staffing requirements and personnel. Describe the methods by which the vendor will analyze staffing requirements and personnel constraints and requirements early in system acquisition and how the results will be used in the design process to meet staffing and personnel requirements and performance criteria.

k) Training requirements. Describe the methods by which the vendor will analyze training constraints and requirements early in system acquisition and how the results will be used in the design process to meet training requirements and performance criteria.

l) Deliverable data products. Identify and briefly describe each HSI deliverable data product specified in the contract and indicate which ones will be iteratively updated over the life of the contract.

Appendix F.
Resources for HSI Training

MASTERS PROGRAMS:

Naval Postgraduate School		
Masters in Human Systems Integration	Online or Monterey, CA	http://www.nps.edu/or/hsi/
Air Force Institute of Technology		
Masters in Engineering Management (Specialization in Human Factors Engineering)	Online	http://www.afit.edu/ENV/programs.cfm?p=36&a=pd
Masters in Systems Engineering (Specialization in Human Systems Engineering)	Wright-Patterson Air Force Base, OH	http://www.afit.edu/ENV/programs.cfm?p=39&a=pd
Johns Hopkins University		
Masters in Systems Engineering (Specialization in Human Systems Engineering)	Online or Elkridge, MD	https://ep.jhu.edu/programs-and-courses/programs/systems-engineering
Oregon State University		
Masters in Industrial Engineering (Specialization in Human Systems Engineering)	Corvallis, OR	http://mime.oregonstate.edu/academics/grad/ie

CERTIFICATE PROGRAMS:

Naval Postgraduate School		
Certificate in Human Systems Integration	Online	http://www.nps.edu/Academics/DL/DLPrograms/Programs/cert_hsi.html

Missouri University of Science and Technology		
Certificate in Human Systems Integration	Rolla, MO	http://dce.mst.edu/credit/certificates/humansystemsintegration/
Air Force Institute of Technology		
Certificate in Human Systems Engineering	Wright-Patterson Air Force Base, OH	http://www.afit.edu/ENV/programs.cfm?p=43&a=pd
Virginia Polytechnic Institute and State University		
Certificate in Human Systems Integration	Online or Blacksburg, VA	http://www.ise.vt.edu/academics/extended/graduate-certificates/hsi.html
University of California San Diego Extension		
Certificate in Human Systems Integration	San Diego, CA	https://extension.ucsd.edu/programs/customprogram/documents/HSIProgram.pdf

TRAINING COURSES:

Georgia Institute of Technology Professional Education		
Human Systems Integration Training Courses	Atlanta, GA	https://pe.gatech.edu/courses/human-systems-integration
Air Force Institute of Technology		
Human Systems Integration Training Courses	Online or various locations	http://www.acq.osd.mil/se/docs/DoD-HSI-Course-Catalog-Final-Edition2012.pdf
Defense Acquisition University		
Human Systems Integration Training Courses	Online or various locations	http://www.acq.osd.mil/se/docs/DoD-HSI-Course-Catalog-Final-Edition2012.pdf

Appendix G.
Additional Resources

The following references provide further information on the topics listed as well as the section number where the topic is introduced.

1.3.2.3 Integrating HSI into the Systems Engineering Process

Blanchard, B., & Fabrycky, W. (2011). *Systems Engineering and Analysis* (5th ed.). New York: Prentice Hall.

Boehm-Davis, D., Durso, F. & Lee, J. (2015). *APA Handbook of Human Systems Integration*. Washington, DC: American Psychological Association.

Folds, D. (2015). Systems engineering perspective on human systems integration. In Boehm-Davis, D., Durso, F. & Lee, J. D. (Eds.), *APA Handbook of Human Systems Integration*. Washington, DC: American Psychological Association.

INCOSE. (2015). Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities. (Version 4.0). Hoboken, NJ, USA: John Wiley and Sons, Inc.

National Aeronautics and Space Administration [NASA] (2014). Human Integration Design Processes (HIDP). National Aeronautics and Space Administration, International Space Station Program, Johnson Space Center, Houston, Texas. (NASA/TP-2014-218556).

2.2 Program Management and Control

2.2.1 Human Systems Integration Program Plan (HSIPP)

2.2.2 Integrating HSI Practitioners into the Systems Engineering Process

2.2.2.1 System Reviews

2.2.2.2 Integrated Product Teams

Naval Air Warfare Center, Training Systems Division (2013). Integrated Product Teams (IPTs), Teaming, Partnering. In Acquisition Guide. Retrieved July, 2015 from the website: http://www.navair.navy.mil/nawctsd/Resources/Library/Acqguide/acqguide.htm

US Air Force. (2009) Directorate of Human Performance Integration. *Air Force Human Systems Integration Handbook.* Brooks City-Base, TX USA.

2.2.2.3 HSI Requirements

2.2.2.4 Sign off Authority

2.2.2.5 HSI Practitioner Qualifications

NUREG-0711 (2012). Human Factors Engineering Program Review Model. Washington, DC: U. S Nuclear Regulatory Commission. (NUREG-0711, rev3).

Boehm-Davis, D., Durso, F., & Lee, J. (2015). *APA Handbook of Human Systems Integration*. Washington, DC: American Psychological Association.

2.2.3 Program Risk Management

2.2.4 Traceability

2.2.5 Operational Experts

2.2.6 Railroad HSI Expertise

2.3 Analysis

2.3.1 Concept of Operation

National Aeronautics and Space Administration [NASA] (2014). Human Integration Design Processes (HIDP). National Aeronautics and Space Administration, International Space Station Program, Johnson Space Center, Houston, Texas. (NASA/TP-2014-218556).

2.3.2 Operational Contexts and Use Case Scenarios

Patterson, E., Roth, E., & Woods, D. (2010). Facets of complexity in situated work. In E. Patterson & J. Miller (Eds.), *Macrocognition metrics and scenarios.* Burlington, VT: Ashgate Publishing.

2.3.3 Lessons Learned Review

NUREG-0711 (2012). Human Factors Engineering Program Review Model. Washington, DC: U. S Nuclear Regulatory Commission, (NUREG-0711, rev3).

2.3.4 Assignment and Detailed Understanding of Tasks

Bisantz, A., & Roth, E. (2008). Analysis of Cognitive Work. In D. Boehm-Davis (Ed.), *Reviews of Human Factors and Ergonomics* (3), pp. 1-43. Santa Monica, CA: Human Factors and Ergonomics Society

Charlton, S. G. (2002). Measurement of cognitive states in test and evaluation. In Charlton, S. G., & O'Brien, T. G. (Eds.). Handbook of Human Factors Testing and Evaluation (2nd Ed.). Mahwah, NJ: Erlbaum.

Crandall, B., & Hoffman, R. (2013). Cognitive Task Analysis. In J. Lee & A. Kirlik (Eds.), *The Oxford Handbook of Cognitive Engineering*. New York, NY: Oxford University Press.

Dekker, S., & Woods, D. (2002). MABA-MABA or Abracadabra? Progress on human-automation coordination. *Cognition, Technology and Work,* (4), 240-244.

De Winter, J., & Dodou, D. (2014). Why the Fitts list has persisted throughout the history of function allocation. *Cognition, Technology and Work,* (16), 1-11.

Endsley, M. (2015). Human Systems Integration Requirements Analysis. In D. Boehn-Davis, F. Durso, & J. Lee (Eds.), *APA Handbook of Human Systems Integration*. Washington, D.C.: American Psychological Association.

Feigh, K., & Pritchett, A. (2014). Requirements for effective function allocation. A critical review. *Journal of Cognitive Engineering and Decision Making,* (8), 23-32.

Gawron, V. J. (2008). Human Performance, Workload, and Situational Awareness Measures Handbook. CRC Press: New York.

Kirwan, B. and Ainsworth, L. (1992). *A guide to task analysis*. Boca Raton, FL: CRC Press, Taylor & Francis group.

Parasuraman, R., Sheridan, T., & Wickens, C. (2000). A model of types and levels of human interaction with automation. *IEEE Transaction Systems, Man and Cybernetics,* (A30), 286-297.

Pew, R. & Mavor, A. (2007). *Human-System Integration in the System Development Process: A New Look*. Washington, DC, USA: The National Academies Press.

Rose, J., Bearman, C., & Maddock, A. (2013). Applying the theories and measures of situation awareness to the rail industry. In Bearman, C., Naweed, A., Dorrian, J., Rose, J., and Dawson, D. (Eds.) *Evaluation of Rail Technology: A Practical Human Factors Guide.* Ashgate, United Kingdom.

Rose, J., Bearman, C., & Naweed, A. (2013). Using task analysis to inform the development and evaluation of new technologies. In C. Bearman, A. Naweed, J. Dorrian, J. Rose, & D. Dawson (Eds.), *Evaluation of Rail Technology: A Practical Human Factors Guide*. United Kingdom: Ashgate.

Roth, E., & Bisantz, A. (2013). Cognitive work analysis. In J. Lee & A. Kirlik (Eds.), *The Oxford Handbook of Cognitive Engineering*. New York: Oxford University Press.

Stanton, N. and McIlroy, R. C (2015). Specifying system requirements using cognitive work analysis. In Boehm-Davis, D., Durso, F. & Lee, J. (Eds.), *APA Handbook of Human Systems Integration*. Washington, DC: American Psychological Association.

Vu, K.-P. L. & Chiappe, D. (2015). Situation awareness in human systems integration. In Boehm- Davis, D. A., Durso, F. T. & Lee, J. D. (Eds). *APA Handbook of Human Systems Integration*. Washington, DC: American Psychological Association.

Wickens, C. & Tsang, P. S. (2015). Workload. In Boehm-Davis, D. A., Durso, F. T. & Lee, J. D. (Eds). *APA Handbook of Human Systems Integration*. Washington, DC: American Psychological Association.

Wickens, C. and Tsang, P. (2015). Workload. In J. D. Lee and A. Kirlik (Eds.), The

Oxford Handbook of Cognitive Engineering. New York: Oxford University Press, Inc.

2.3.6 Tradeoff Analyses

Barnes, M. & Beevis, D. (2003). Human systems measurements and trade-offs in system design. *Handbook of Human Systems Integration,* H.R. Booher (ed.), Wiley & Sons, Inc.

Federal Aviation Administration (2009). Requirements for a Human Factors Program (HF-STD-004). Washington, D.C.

INCOSE. (2015). Technical management processes. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*, version 4.0. Hoboken, NJ, USA: John Wiley and Sons, Inc.

2.4 Design and Development

2.4.1 Work Environment Design

ANSI/HFES 100-2007 Human Factors Engineering of Computer Workstations.

ANSI / HFES 200 Human Factors Engineering of Software User Interfaces.

DoD (2012). Military Standard: human engineering design criteria for military systems, equipment, and facilities (MIL-STD-1472G). Virginia: Defense Technical Information Center.

Stanton, N. A., Salmon, P., Jenkins, D. & Walker, G. (2010). Human Factors in the Design and Evaluation of Central Control Room Operations. Boca Raton, FL: CRC Press.

2.4.2 Human Computer Interface/Software Design

Bennet, K. & Flach, J. (2011). *Display and Interface Design*. Boca Raton, FL: CRC Press.

Burns, C. and Hajdukiewicz, J. (2004). *Ecological Interface Design*. Boca Raton, FL: CRC Press.

Endsley, M., & Jones, D. (2012). *Designing for Situation Awareness: An approach to user-centered design.* Boca Raton, FL: CRC Press.

Evenson, S., Muller, M., & Roth, E. (2008). Capturing the context of use to inform system design. *Journal of Cognitive Engineering and Decision Making, 3*, 181-203.

Hughes, G., Long, A., Maddock, A., & Bearman, C. (2013). Effective User Feedback: The Practical Value of Mock-ups. In C. Bearman, A. Naweed, J. Dorrian, J. Rose, & D. Dawson (Eds.), *Evaluation of Rail Technology: A Practical Human Factors Guide*. United Kingdom: Ashgate.

Meyer, J., & Lee, J. (2013). Trust, Reliance and Compliance. In J. Lee & A. Kirlik

(Eds.), *The Oxford Handbook of Cognitive Engineering*. New York, NY: Oxford University Press.

Sarter, N. (2013). Multimodal displays: Conceptual basis, design guidance, and research needs. In J. Lee and A. Kirlik (Eds.), *The Oxford Handbook of Cognitive Engineering*. New York, NY: Oxford University Press.

Sheridan, T. (2015). *APA Handbook of Human Systems Integration* (F. Boem-Davis & J. Lee, Eds.). Washington, D.C.: American Psychological Association.

Shneiderman, B., Plaisant, C., Cohen, M. & Jacobs, S. (2010). Designing the User Interface: Strategies for Effective Human-Computer Interaction (5th Edition). Boston, MA: Addison- Wesley.

2.5 Test and Evaluation (T&E)

Bearman, C., Naweed, A., Dorrian, J., Rose, J., & Dawson, D. (2013). *Evaluation of Rail Technology: A Practical Human Factors Guide.* United Kingdom: Ashgate.

Charlton, S., & Obrien, T. (Eds.). (2002). *Handbook of human systems integration testing and evaluation* (2nd ed.). Mahwah, NJ: Erlbaum.

National Aeronautics and Space Administration [NASA] (2014). Human Integration Design Handbook (HIDH). (NASA/SP-2010-3407/REV1). Washington DC.

Patterson, E., & Miller, J. (2010). *Macrocognition metrics and scenarios: Design and evaluation for real-world teams*. Burlington, VT: Ashgate Publishing Limited.

Wilson, J., & Sharples, S. (2015). *Evaluation of Human Work* (4th ed.). Boca Raton, FL: CRC Press.

Abbreviations and Acronyms

AAR	Association of American Railroads
CFR	Code of Federal Regulations
DoD	Department of Defense
ECP	Electronically Controlled Pneumatic (brakes)
EM	Energy Management
FAA	Federal Aviation Administration
FRA	Federal Railroad Administration
HED	Human Engineering Discrepancy
HFE	Human Factors Engineering
HMI	Human-Machine Interface
HSI	Human Systems Integration
HSIPP	Human Systems Integration Program Plan
INCOSE	International Council on Systems Engineering
IPT	Integrated Product Team
MANPRINT	Manpower and Personnel Integration
NASA	National Aeronautics and Space Administration
PTC	Positive Train Control
RFI	Request for Information
RFP	Request for Proposal
ROI	Return on Investment
SA	Situation Awareness
SE	Systems Engineering
SME	Subject Matter Expert
SOW	Statement of Work

T&E	Test and Evaluation
TCO	Total Cost of Ownership