Systematic Approach to Assessing the Readiness of a Technology for Safe and Effective Human Use

Opportunities to Integrate Human Readiness Levels (HRLs) in Federal Aviation Administration (FAA) Research, Acquisition, and System Development Processes

Edward Austrian, Michael Sawyer, Jason Kring, Kevin Siragusa
Fort Hill Group
Washington, DC USA
Eddie.Austrian@FortHillGroup.com

Tara Gibson
Human Factors Division
Federal Aviation Administration
Washington, DC USA

Systems moving through the development and acquisition process must demonstrate increasing levels of maturity and safety as they move closer to implementation in the National Airspace System. Multiple required activities must be completed to demonstrate how "ready" or mature the system is prior to implementation. This includes addressing questions around user involvement and operational readiness such as: how are human-integration challenges addressed? How are the differences in human performance captured throughout the development lifecycle? In September of 2021, the American National Standards Institute (ANSI) and the Human Factors and Ergonomics Society (HFES) published the Human Readiness Level (HRL) scale as the ANSI/HFES Standard 400-2021, "Human Readiness Level Scale in the System Development Process." The HRL scale is used to assess, track, and convey the readiness of a system for human use. It is intended to supplement the existing technology readiness level (TRL) scale developed by National Aeronautics and Space Administration (NASA), which measures and communicates the maturity of a technology. This research provides a methodology to tailor the HRL scale to an existing process for research, acquisition, and system development. It also identifies specific opportunities to align existing human factors work activities and output data with the HRL scale. Results could provide a basis for using the HRL scale as an enhancement to an existing process without changing it. Based on the literature reviewed, the Federal Aviation Administration (FAA) is the first civil aviation authority (CAA) in the world to advance the use of HRLs in this context since the scale was codified in September 2021.

Keywords: acquisition; readiness, human factors, safety

I. Introduction

The Federal Aviation Administration (FAA) maintains a robust process for air traffic control research, acquisition, and system development. It provides several mechanisms to evaluate and monitor a technology or system throughout design, development, and deployment. Acquisition programs commonly use a technology readiness assessment to determine the maturity of a technology or system at a point-in-time. Understanding the state of human factors integration is not the primary focus of a technology readiness assessment.

The successful integration of technology and procedures in national airspace system (NAS) operations relies on a human-centered approach. Appropriate integration of human factors can support the development of technology that is ready for safe and effective use by a target population in actual operating environments. Further, it may reduce operating costs, the need for rework, and certain post-implementation modifications. The publication of the ANSI/HFES Standard 400-2021, "Human Readiness Level Scale in the System Development Process" provides an adaptable framework to enhance the ability to evaluate the state of human factors integration, track work complete, and communicate the degree to which a system is ready for safe and effective use at any point in a development process [1].

A. Background

A technology readiness assessment (TRA) is a systematic review of data aimed at better understanding the maturity of a critical technology element (CTE). TRA results can indicate the degree to which a CTE might address acquisition program objectives at a point-in-time. According to FAA documentation, use of the term, CTE, indicates that a proposed technology, or its application thereof, is considered new or novel. This perspective highlights the importance of compiling appropriate data for TRAs and effectively communicating the results to a broad audience. Various organizations have adapted and use readiness level scales to improve TRA effectiveness [2].

Multiple readiness level scales have been developed to convey different aspects of CTE maturity. The Technology Readiness Level (TRL) scale developed by National Aeronautics and Space Administration (NASA) is the most widely cited and applied [2]. While the TRL scale is a well-established measure, it does not directly consider if a technology is mature enough for safe and effective use by a target population. To fill this gap the American National Standards Institute (ANSI) and Human Factors and Ergonomics Society (HFES) published the Human Readiness Level (HRL) scale as the ANSI/HFES Standard 400-2021, “Human Readiness Level Scale in the System Development Process [1].

Like TRLs, the HRL scale requires data and demonstration to inform a readiness determination. Numerous scientific and technical reports explain the reasons that it is beneficial to adapt readiness level scales, but there is a paucity of guidance on how to do it. This research provides a methodology to tailor the HRL scale to an existing process for air traffic research, acquisition, and system development. It also identifies specific opportunities to align existing human factors work activities and output data with the HRL scale. Results can provide a basis for using the HRL scale as an enhancement to an existing process without changing it. Based on the public literature reviewed, FAA is the first civil aviation authority (CAA) in the world to advance the use of HRLs in this context since the scale was codified in September 2021. This paper presents four sets of related analyses. As a collection, the results can provide a basis for tailoring and adapting the HRL scale. The contents and organization of information in this paper are in the list below.

- **Section II: Literature Review and Assessment** describes the origin, evolution, and state of HRLs.
- **Section III: Review and Analysis of ANSI/HFES 400-2021** summarizes the HRL scale and a methodology for mapping HRLs to an existing process.
- **Section V: Review of the Acquisition Management System** introduces an existing FAA process for air traffic research, acquisition, and system development.
- **Section VI: Analysis and Results** shows the mapping of HRLs to an existing FAA process and potential benefits.

II. Literature Review and Assessment

A literature review was completed between February 2022 and November 2022. It focused on the assessment of technical reports, scientific journal articles, and professional conference presentations published between 2010 and 2022 that specifically cited HRLs. The intent was to understand the provenance of human readiness levels, activities leading up to the development of ANSI/HFES 400-2021, and potential implementations.

A. Human readiness levels: origin, development, evolution

Drivers for integrating the human element in an aviation system design process pre-date World War II. Innovations in aircraft design and flight deck layout did not always consider human capabilities or limitations. Inconsistent design within and across manufacturers reportedly led to military pilot errors and aircraft accidents. In response, the United States (U.S.) military documented some of the first human factors engineering (HFE) standards. During space and missile programs in the late 1950s and 1960s, the U.S. military established more cohesive and comprehensive standards for the design of visual displays, operator controls, body size accommodations, operating environments, and other topics [3]. For example, in 1968, the U.S. Military released the Military Standard 1472 (MIL-STD-1472) *Human Engineering Design Criteria for Military Systems, Equipment, and Facilities.* The first iteration provided requirements and guidance for considering the human characteristics of a system operator and maintainer in a design. The U.S. Military released Version H of MIL-STD-1472 in 2020 [4].

In 1984, the U.S. Army established a proactive approach to human integration in system design with the Manpower and Personnel Integration (MANPRINT) program. This program facilitates early consideration of human capabilities and training needs in system design and evaluation. Savage-Knepshield [5] noted that MANPRINT forced a change in how defense contractors did business with the Army, requiring a greater focus on the human users and designing systems to better fit soldiers’ needs and capabilities. MANPRINT, along with programs for the U.S. Navy (SEAPRINT) and U.S. Air Force (AIRPRINT), continued to evolve [6]. Today, each branch of the U.S. military has its own version, now called Human Systems Integration (HSI) [7].

Even with the availability of standards and documents to support HSI, and the inclusion of requirements to employ HSI in the DoD system development process, there remained little guidance on achieving this goal. For example, the 2013 version of the DoD Instruction 5000.02 Operation of the Adaptive Acquisition Framework had two pages in the 151-page document dedicated to HSI. The most recent update [8], [9] includes more guidance but does not specify how organizations should test and verify HSI.

Another challenge with implementing HSI in the system development process is variability between systems. The testing and validation approach used for one system, for example, the flight deck of a military aircraft, may be quite different from the approach used for a helmet-mounted display. Furthermore, comparing the level of HSI between systems or at different points in the design process is complicated and lacks a more generic approach that can be used and interpreted by multiple organizations.

Acosta [10], [11] proposed a Human Readiness Level framework that evaluates system design regarding human capabilities and limitations in the technology maturity assessment process. Acosta modeled the HRL concept on Technology Readiness Levels (TRLs), first introduced by the National Aeronautics and Space Administration (NASA) in the mid-1970s, as a discipline-independent program to allow more effective assessment and communication regarding the maturity of new technologies [12]. The goal of HRLs was to reduce technology risks associated with the human element by including HSI in technology maturity evaluations.

Building on this concept, the Naval Postgraduate School sponsored two master’s theses focused on HRLs. In the first thesis, Phillips developed the framework for a nine-level HRL scale and collected feedback from HSI and defense acquisition subject matter experts (SMEs) [13]. Phillips also conducted a retrospective case study to determine if HRLs would have contributed positively to the acquisition and development process for the U.S. Air Force Ground Control Station Modernization (GMOD) program. In the second thesis, O’Neil

[5], [14] developed the Comprehensive Human Integration Evaluation Framework (CHIEF) for the United States Coast Guard to provide the acquisition community with a viable tool for assessing HSI throughout the design and development process. CHIEF was designed to communicate a system-level discussion of HSI in terms of total system performance by categorizing the degree to which HSI performance observed in each HSI domain used by the Coast Guard (e.g., Personnel, Training, Human Factors Engineering) either enhanced or degraded total system performance.

The evolution of the HRL scale continued during Dr. Mica Endsley's tenure as Chief Scientist of the United States Air Force (2013-2015), during which time she led a DOD HSI Technical Advisory Group (TAG) to refine the scale [15]. This group, comprised of over 20 U.S. military, FAA, NASA, and academia representatives, added detailed descriptions and relevant supporting information for each of the nine human readiness levels. In 2019, Sandia National Laboratories, the Naval Postgraduate School, and Old Dominion University led a second working group to mature the HRL scale, which involved 38 different organizations from DOD, NASA, FAA, industry, and academia [16], [17]. The working group also supported research focused on the utility, usability, validity, and reliability of the HRL scale. For example, See, Craft, and Morris [18] investigated the utility of the HRL scale for nuclear weapons programs at Sandia National Laboratories. Through SME interviews, the authors captured feedback on which of four options would work best to assess human readiness: 1) Separate HRL scale, 2) TRL+ (TRL with added human readiness concepts), 3) Human Factors Realize Product Procedure (RPP), and 4) an HSI Risk Tool. Results from this study revealed a preference for the TRL+ scale approach. In another study, Handley and Savage-Knepshield [19] verified the utility of the HRL scale and supporting questions by applying the HRL method to a previous program of record, the U.S. Army Tactical Network system, for which a series of Human System Integration Assessments (HSIA) was available.

Other efforts by the second working group included workshops to evaluate the usability and inter-rater reliability of the HRL scale and two approaches at validation. The first involved mapping HRLs to existing HSI standards, including the NUREG-0711 Human Factors Engineering Program Review Model [20], the United Kingdom's Joint Service Publication (JSP) 912 Human Factors Integration for Defense Systems [21], SAE6906 Standard Practice for Human Systems Integration [22], and ISO 9241 220 Ergonomics of Human-System Interaction — Part 220: Processes for Enabling, Executing and Assessing Human-Centered Design within Organizations [23].

The second validation approach compared HRLs to multiple HSI tools and similar human readiness approaches to find gaps, linkages, and consistencies [16]. For example, Hale, Fuchs, Carpenter, and Stanney proposed a scale of Human Factors Readiness Levels (HFRL) to provide a method for standardizing HF readiness assessment [24]. The HFRL scale can be used by decision makers in acquisition, project management, or implementation phases in conjunction with TRLs, and includes HF-specific level descriptions and evaluation requirements. The HFRL scale was also integrated into a software tool, the System for Human Factors Readiness Evaluation (SHARE), to track, calculate, and communicate HFRLs to support acquisition decision-making and product development [25]. Another human readiness approach evaluated by the working group is the Human Readiness Assessment (HRA), which measures quantitative maturity in terms of situation awareness, usability, and workload [26]. This tool was created to use TRLs and HRLs and maps directly to each.

The activities above culminated in the establishment of an HRL standard writing committee in September 2020 [27]. The 10-member committee, chaired by Judi E. See of Sandia National Laboratories, was represented by personnel from the government (FAA, Navy Expeditionary Combat Command), industry (General Motors, Northrop Grumman, SA Technologies), academia (Johns Hopkins Applied Physics Laboratory), and HFES. Although the primary goal was to generate the final ANSI/HFES technical standard, the committee also developed ideas that lent legitimacy to the scale, promoting acceptance, provided a reference to support HRL use in formal programs of record, and generated awareness of HRLs beyond the HSI community.

In summary, the origin and evolution of HRLs began in 2010 and culminated with the publication of the HRL standard (ANSI/HFES STD 400-2021) in September 2021 [1]. Between these two milestones, working groups, research studies, and related activities have helped to define, refine, and mature the HRL scale. Furthermore, the working group compared HRLs with similar concepts, such as the Human Factors Readiness Levels (HFRL) [20], the Human Readiness Assessment (HRA) [26], and related tools like the Comprehensive Human Integration Evaluation Framework (CHIEF) [5], [14] and the System for Human Factors Readiness Evaluation (SHARE) [25].

B. Implementations of the HRL scale in current operations

HRL implementations cited in the identified literature were limited to 14 retrospective case studies. In other words, researchers evaluated how an acquisition and system development process could have been affected if HRLs were applied. Contrast this with proactive implementations. None of the reports identified suggested that an organization has fully integrated HRLs into a large-scale acquisition process, and successfully applied them from the beginning. A summary of the retrospective case studies is provided in the table below.

TABLE I. RETROSPECTIVE APPLICATIONS OF THE HRL SCALE

Topic	**Retrospective case studies**
HRL outpaces TRL	• Traditional software development • Agile software development
TRL outpaces HRL	• Maintenance inspection robotic system • Advanced field artillery tactical data system
General HRL use and demonstration	• Helmet mounted display (HMD) system • Upgrade to existing HMD system • Military leadership training system
Benefits case for using HRLs	• U.S. Army Stinger Missile program • Large scale weapon component • Predator ground control station • Motor lifeboat • Emergency egress lighting system

Key takeaways from the case studies include: 1) HRL benefits may not be fully realized if investments in research and system development exclude or outpace the execution of human factors activities; 2) the earlier HRLs are implemented, the more effective they may be guiding decisions that maximize the human element; and 3) late integration of HRLs into a development process may have less of a positive impact on the overall human readiness of a fielded system.

III. REVIEW AND ANALYSIS OF ANSI/HFES 400-2021

An extensive review of the published Standard, including all supporting appendices, was conducted to develop a base understanding of the HRL scale as codified in 2021. The review focused on intended use of the Standard and information required to map HRLs to an existing system development process. If a clear mapping is established, the HRL scale can be used as an overlay to an existing process. This means it can facilitate bidirectional traceability between the human factors data required and the actual data produced, thereby enhancing awareness of the state of human factors integration during a development effort.

A. Intended use of the Standard

ANSI/HFES 400-2021 provides informative guidance on how to use the HRL scale. It defines objectives for each human readiness level and criteria to measure the degree to which an HRL objective is met. The Standard does not prescribe how to gather human factors data, the conduct of human engineering activities, or the use of automatic tools to calculate an HRL. However, it does encourage an organization to identify the contributions of existing research, acquisition, and system development processes to the HRL scale. Results can provide a basis to use the HRL scale as a process enhancement, not a replacement.

ANSI/HFES 400-2021 includes explicit statements about its intended use. These statements offer implicit assumptions about personnel qualifications, the appropriate use of evaluation criteria, and acceptable tailoring of specifications to an existing process. Anecdotal evidence has suggested that the Standard may be used by a broad range of people with varying amounts of human factors knowledge, training, experience, responsibilities, and resources. This variability can influence conformance to the Standard and intended purpose of the HRL scale. A brief summation of key assumptions is below.

- **Knowledge:** Trained and knowledgeable human systems experts, hereafter experts, will apply the HRL scale.
- **Qualifications:** Qualified experts will tailor specifications in the Standard to their mission needs.
- **Experience:** Experts will apply their expertise and experience to tailor the Standard.
- **Applicability:** Not all evaluation activities are appropriate or applicable for every system.
- **Tailoring:** Experts will specify evaluation activities (questions) that must be addressed to demonstrate an HRL.

B. Human readiness level scale

ANSI/HFES 400-2021 defines the nine levels of human readiness. Each level is a measurement of the degree to which a technology meets a defined program objective at a point-in-time; specifically, the readiness of a technology for safe and effective human use. Table II lists each HRL as defined in the Standard. It is clear that, as HRLs increase, the state of human factors integration becomes more distinguished with a shift towards understanding interactions between a target population and a technology in actual operating conditions, environments, and procedures.

TABLE II. HRL SCALE AS DEFINED IN ANSI/HFES 400-2021

HRL Level	**Description**
1	Basic principles for human characteristics, performance, and behavior observed and reported
2	Human-centered concepts, applications, and guidelines defined
3	Human-centered requirements to support human performance and human-technology interactions established
4	Modeling, part-task testing, and trade studies of human systems design concepts and applications completed
5	Human-centered evaluation of prototypes in mission-relevant part-task simulations completed to inform design
6	Human systems design fully matured as influenced by human performance analyses, metrics, prototyping, and high-fidelity simulations
7	Human systems design fully tested and verified in operational environment with system hardware and software and representative users
8	Total human-system performance fully tested, validated, and approved in mission operations, using completed system hardware and software and representative users
9	System successfully used in operations across the operational envelope with systematic monitoring of human-system performance

C. Data extraction for mapping HRLs

ANSI/HFES 400-2021 provides informative guidance about the HRL scale in Appendix C. This guidance spans five topics: evaluation guidance, evaluation activities, guidance and considerations, exit criteria, and supporting evidence. As illustrated in Table III, this guidance provides a performance-based framework to adapt and use the HRL scale.

TABLE III. SUMMARY OF INFORMATIVE GUIDANCE ON HRLS

Informative guidance	Intended purpose
Evaluation guidance	Defines characteristics of each HRL
Evaluation activities	Lists questions to prompt a review of data
Guidance and considerations	Clarifies the intent of evaluation activities
Exit criteria	Basis for decisions to move between HRLs
Supporting evidence	Types of data that might inidicate readiness

Evaluation activities are an important element of the HRL scale; they facilitate bidirectional traceability between human factors data required and the actual data produced throughout a system development process. This can be accomplished if there is a clear mapping between each HRL evaluation activity and sections of an artifact or output product whereby human factors data may be recorded by program. For this reason, all evaluation activities were extracted from the Standard. Fifteen categories were created to group related evaluation activities across HRLs. The categories align with FAA terminology and conform to the intent of ANSI/HFES 400-2021. Each category includes between 3 and 9 evaluation activities. These categories and the number of evaluation activities assigned to each in the list below.

- Human Capabilities (n=3)
- Research and Analysis (n=5)
- Usage Scenarios and Testing (n=8)
- Human Performance and Safety (n=9)
- Human Performance System Requirements (n=9)
- Human Performance Metrics (n=8)
- Design for Human Use (n=6)
- Task Analysis (n=6)
- Environmental Conditions (n=6)
- Function Allocation (n=7)
- Maintenance Interactions (n=6)
- Personnel and Training (n=9)
- Modeling and Prototypes (n=3)
- Procedures (n=5)
- Issue Tracking (n=4)
- Habitability and Survivability (n=6)

It is important to note the *Habitability and Survivability* category was not deemed relevant to FAA-provided services and systems. This HRL evaluation category was not included in any additional analysis.

IV. REVIEW OF THE ACQUISITION MANAGEMENT SYSTEM

A comprehensive review of acquisition management system (AMS) policy and guidance was completed. It focused on the purpose, sequence, and timing of human factors activities and data produced across the research, acquisition, and system development process. The intent was to identify artifacts that can serve as possible sources for each HRL evaluation activity.

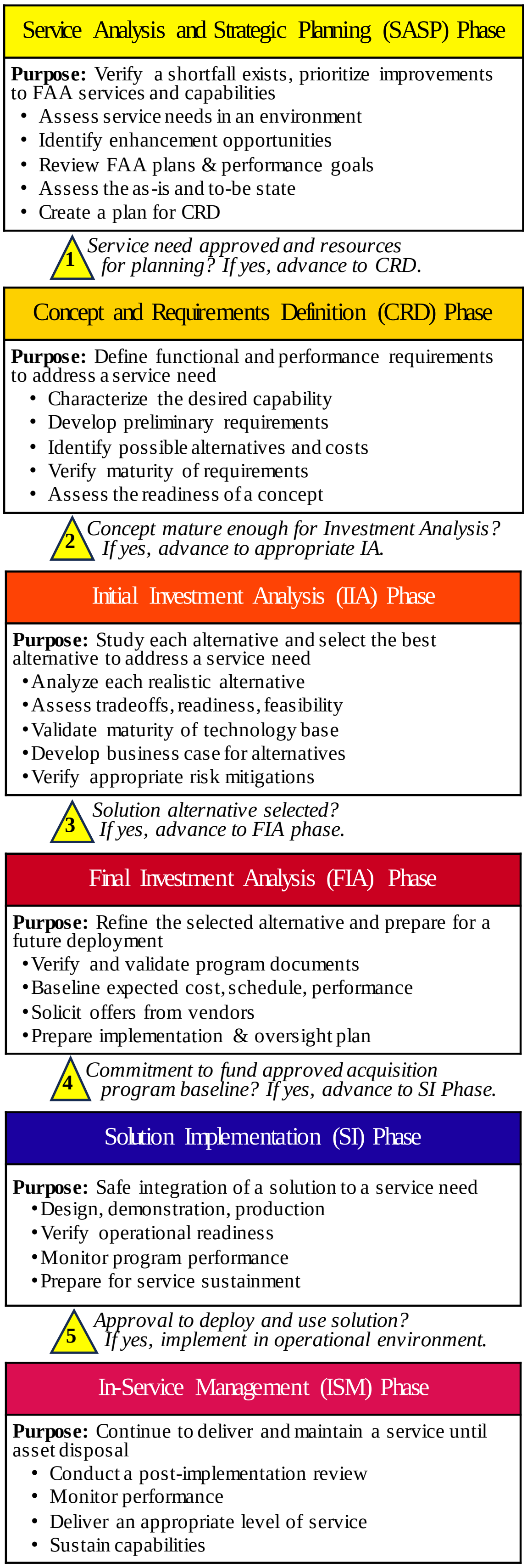

Figure 1. Example summary of the AMS process

A. *Research, acquisition, and system development process*

In 1995, Public Law (PL) 104-50 required FAA to establish an acquisition management system (AMS). This mandate directed FAA to set agency-specific policy and guidance to allows enhancement to investment quality and efficiency. In 1996, FAA implemented AMS, and it is still in use today.

AMS policy prescribes requirements that are applicable to all FAA appropriations and investments with limited exception [28]. AMS policy requires the integration of human factors throughout research, acquisition, and system development. AMS guidance expands, illustrates, and assists FAA personnel who implement, use, and oversee AMS policy. Example types of guidance with human factors information includes but is not limited to FAA approved instructions, templates, checklists, manuals, handbooks, and standards [29].

FAA organizes research, acquisition, and system development into six phases; each phase has a distinct purpose. AMS policy provides a basis for each phase of a potential investment while guidance clarifies expectations for work activities, coordination efforts, updates to artifacts, output products, technical reviews, assessments, and decision points (DPs) [29]. Figure 1 illustrates the sequence of each phase, the timing of DPs, and example intent of data produced.

B. *Identification of documents for mapping to HRLs*

Ninety-nine AMS policy and guidance documents were obtained from the FAA Acquisition System Toolkit [30]. The documents were sorted into two groups: approved input documents (*n*=99) to a phase, process, or work activity, and approved output documents (*n*=71) that may provide a record of results. Each document was reviewed to determine if human factors data or proof of demonstration might be recorded. In total, 45 of 99 documents reviewed met these criteria. Most of the resulting documents were templates that clarify and shape the general content of artifacts and output products. These documents provided a foundation for mapping the HRL evaluation activities to an existing process.

TABLE IV. AMS DOCUMENTS REVIEWED

Document type	Number of reviewed
Guidance Documents	**39** Documents
Templates	**40** Documents
FAA Orders	**6** Documents
Standards	**4** Documents
Tools / Toolkits	**3** Documents
Checklists	**3** Documents
Policy Documents	**2** Documents
Other Material	**2** Documents
Total	**99** Documents

V. ANALYSIS AND RESULTS

A multidisciplinary team of qualified subject matter experts conducted a comparative analysis of evaluation activities and AMS documentation to inform potential opportunities to adapt the HRL scale to an existing process. Team members included human factors researchers with doctoral degrees, a data scientist, enterprise architect, and aviation systems analyst. All team members have varying degrees of experience with AMS policy and guidance from a human factors perspective.

A. *Assumptions*

Four primary assumptions were used throughout this research.

1. The HRL scale does not require use of the TRL scale; therefore, the HRL scale can enhance other measures of technology maturity.
2. It is not always appropriate for technology and human readiness to progress equally.
3. In practice, levels of human readiness may progress, plateau, and even regress during system development process.
4. The circumstances surrounding human factors and engineering activities, data, and other information are understood.

B. *Methods, tools, and summation of results*

A comparative analysis of 100 evaluation activities and 45 AMS documents was completed to determine if there was a relationship between the HRL scale and an existing system development process. A traceability matrix was developed to document potential relationships between evaluation activities and human factors information in an AMS document.

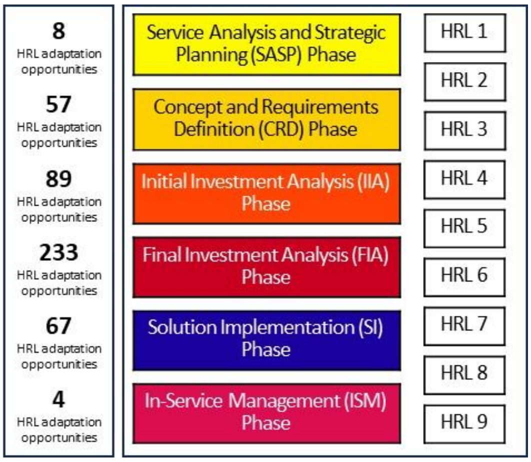

Figure 2 Total number of potential HRL mappings

MAXQDA was used to support the classification and grouping of qualitative data, as well as the development of a hierarchical data structure within and across documentation, for example: HRL categories, evaluation activities, and specific text of an AMS document. The data structure helped visualize potential opportunities to adapt the HRL scale to an existing process.

Overall, 91 of the 100 evaluation activities had a direct or conditional mapping across the 45 AMS documents. There are six evaluation activities associated with the Habitability and Survivability category that were deemed not to apply to FAA air traffic systems and did not have an associated adaptation opportunity. Three additional evaluation activities that were assessed did not map to an AMS document. These include *C.8.1.2 Have task analyses been updated with the production system in mission operations, C.9.1.6 Are potential upgrades to the fielded system being evaluated to address human systems issues and impacts*, and *C.9.1.7 Are potential programmatic, mission, or operational changes to the fielded system being evaluated to address human systems issues and impacts.* Arguably, these evaluation activities do not align with the intended purpose of the system development process and are therefore addressed through other mechanisms.

Individual evaluation activities may map to AMS documentation across multiple AMS phases. Figure 3 provides a breakdown of the number of unique evaluation activity mappings across AMS phases for each HRL evaluation categories. The number of unique evaluation activities peaks during FIA where adaptation opportunities were identified for 75 of the 100 evaluation activities.

Evidence from this research indicated a robust presence of human factors across AMS documents reviewed. The large number of HRL adaptation opportunities and broad distribution of human factors information across AMS documents suggest there are many ways in which existing FAA processes could be enhanced by HRLs, and the degree to which development efforts can produce systems that promote safe, effective human use. Within the context of this effort, a near-term benefit that HRLs may offer is bidirectional traceability between the human factors data required and the actual data produced at points-in-time. This benefit is predicated on a clear mapping of the HRL scale to an existing process. Below is a further illustration of the potential benefits.

HRL Evaluation Category	SASP	CRD	IIA	FIA	SI	ISM
Human Capabilities	3	3	3	3	3	
Research and Analysis	1		2	4	4	
Usage Scenarios and Testing		3	5	5	5	
Human Performance and Safety	2	4	6	7	8	1
Human Performance System Requirements	1	2	1	6	2	1
Human Performance Metrics		2	2	6	1	1
Design for Human Use		2	3	5	3	
Task Analysis		1	4	5	4	
Environmental Conditions		2	2	6	1	
Function Allocation		2	4	6	1	
Maintenance Interactions		2	4	6	1	1
Personnel and Training	1	2	4	6	2	
Modeling and Prototypes			3	3	3	
Procedures		1	2	3	3	
Issue Tracking			2	4	2	
Habitability and Survivability						
Unique Evaluation Activities per Phase	**8**	**26**	**47**	**75**	**43**	**4**

Figure 3 Number of unique evaluation activity mappings per AMS phase

HRLs can provide additional structure and efficiency: The HRL scale can increase visibility into human factors activities, data, and products produced throughout a large-scale acquisition process. For example, to apply the HRL scale, a series of evaluation activities are addressed; responses are informed by a compilation of data obtained throughout a system development process. Since human factors is a multidisciplinary field, appropriate data could be produced by a collection of lower-level assessments. Data from these assessments might be reported across several point-in-time documents. This may cause difficulties when attempting to locate correct sources of data for assessment, compiling appropriate data, and tracking the state of human factors integration throughout a large-scale acquisition process. With the establishment of a clear mapping system, the HRL scale can be used as an overlay to an existing process; that might mitigate these difficulties.

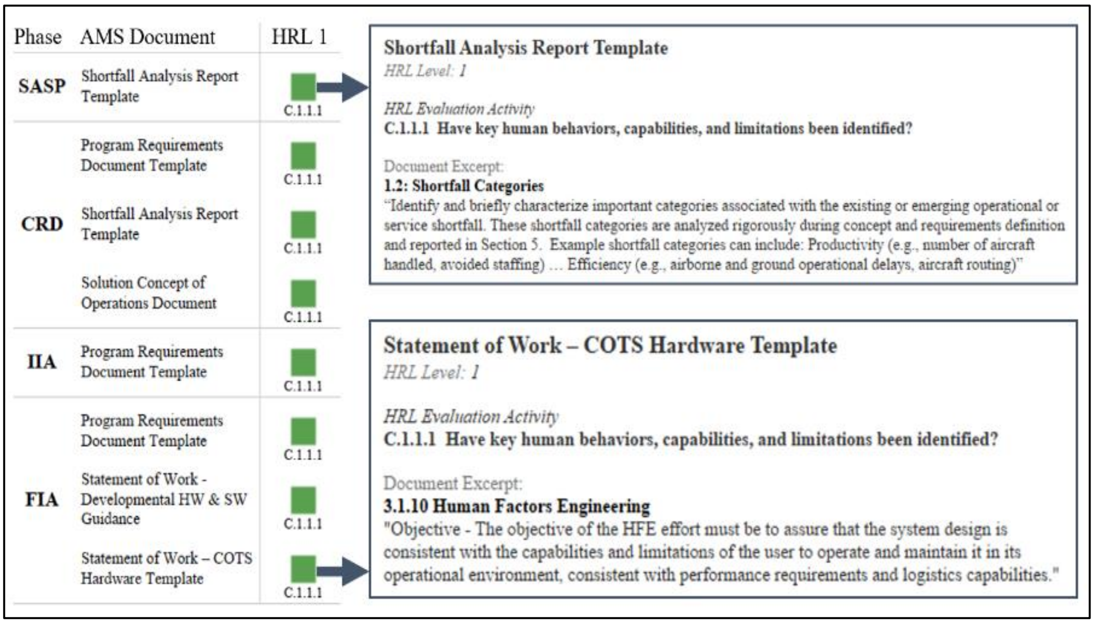

Figure 4. Example illustration of bidirectional traceability

HRLs can enhance tracking and improve awareness: A number of development efforts may depend on the transfer of technology within and across agencies. For example, NASA successfully transferred air traffic technology demonstrations to FAA's time-based flow management (TBFM) system; a technology that is similar in nature to arrival management (AMAN), which supports air traffic scheduling and metering. Further, multiple organizations may oversee different phases of a development process; therefore, several transfers may occur. The HRL scale can enhance tracking and awareness of the state of human factors integration throughout all aspects of system development, including technology transfers. As illustrated in Figure 4, HRLs can provide a repeatable, transparent framework to track the progression of human factors data and demonstration throughout a development.

VI. Conclusion

The HRL scale can be adapted and used within a large-scale acquisition process, such as AMS. Evidence indicated a robust presence of human factors across AMS documents reviewed. The large number of HRL adaptation opportunities and broad distribution of human factors information across AMS documents suggests there are many ways in which existing FAA processes could be enhanced by HRLs, as well as the degree to which development efforts can produce systems that promote safe, effective human use. A comparison of HRL phases to AMS phases showed strong alignment between the objectives and sequence of each. The HRL scale can increase FAA visibility into human factors activities and corresponding products throughout AMS. Within the context of this effort, a near-term benefit that HRLs may offer would be bidirectional traceability between the human factors data required and the actual data produced. This benefit is predicated on a clear mapping of the HRL scale to an existing process. Next steps for this research may include retrospective case studies and proactive applications of the HRL scale. The intent is to refine the methodology proposed in this paper and provide a research basis for potential implementation decisions.

Acknowledgment

This research was completed with funding from the Federal Aviation Administration (FAA) Human Factors Division (ANG-C1) in support of technical sponsors in the Office of NextGen (ANG). The authors thank ANG for sponsoring this research and FAA program managers Karl Kaufmann and Sabreena Azam. The authors also thank Jordan Hinson and Ryan Dlugash for their significant contributions to the execution of this research.

Disclaimer

The views expressed herein do not reflect views of the United States (U.S.) Department of Transportation (DOT), the Federal Aviation Administration (FAA), or names acknowledged.

References

[1] Human Factors and Ergonomics Society (2021). *Human Readiness Level Scale in the system development process* (ANSI/HFES 400-2021). https://www.hfes.org/Portals/0/Documents/DRAFT%20HFES%20ANSI%20HRL%20Standard%201_2_2021.pdf?ver=2021-01-06-142004-860&timestamp=1609964482681

[2] Government Accountability Office. (2020). *Technology readiness assessment guide*. (GAO Publication No. GAO-20-48G). Washington, D.C.: U.S. Government Printing Office.

[3] McDaniel, J., & Chaikin, G. (2003). History of the military human factors engineering standards. *Human Systems IAC Gateway*, *14*(2), 6-7, 22-23. https://apps.dtic.mil/sti/pdfs/ADA487996.pdf#page=17

[4] Department of Defense (2020). *MIL-STD-1472H, Department of Defense Design Criteria Standard: Human Engineering*. https://quicksearch.dla.mil/qsdocdetails.aspx?ident_number=36903

[5] O'Neil, M. (2014). *Development of a human systems integration framework for Coast Guard acquisition* [Master's thesis, Naval Postgraduate School]. https://apps.dtic.mil/sti/pdfs/ADA608012.pdf

[6] Pew, R. W. (2008). Some new perspectives for introducing human-systems integration into the system development process. *Journal of Cognitive Engineering and Decision Making, 2*(3), 165-180. https://acs.ist.psu.edu/ist521/papers/pew08.pdf

[7] United States Army (n.d.). What is Army HSI? U.S. Army Human Systems Integration Program. https://www.armyg1.army.mil/HSI/

[8] Department of Defense (2013). *DoD Instruction 5000.02 Operation of the Adaptive Acquisition Framework*. https://www.acq.osd.mil/fo/docs/DSD%205000.02_Memo+Doc.pdf

[9] Department of Defense (2022). *DoD Instruction 5000.95 Human systems integration in defense acquisition*. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500095p.PDF

[10] Acosta, H. (2010, May 9–13). *Human readiness levels: Implementing HSI – Connecting some dots* [Panel discussion]. 81st Annual Scientific Meeting of the Aerospace Medical Association, Phoenix, AZ, United States.

[11] Kosnik, W., & Acosta, H. (2010, September). HSI as a method for embedding human-centered design in Air Force rapid acquisition programs. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 54, No. 25, pp. 2165-2168). https://journals.sagepub.com/doi/abs/10.1177/154193121005402509

[12] Mankins, J. C. (2009). Technology readiness assessments: A retrospective. *Acta Astronautica*, *65*(9-10), 1216-1223. https://www.sciencedirect.com/science/article/abs/pii/S0094576509002008

[13] Phillips, E. C. (2010). *The development and initial evaluation of the Human Readiness Level framework* [Master's thesis, Naval Postgraduate School]. https://apps.dtic.mil/sti/pdfs/ADA525365.pdf

[14] O'Neil, M. P., Shattuck, L. G., & Sciarini, L. W. (2015). A framework for assessing and communicating human systems integration efficacy across the system lifecycle. *Procedia Manufacturing*, *3*, 3054-3061. https://www.sciencedirect.com/science/article/pii/S2351978915008525

[15] Endsley, M. (2015, February). *Human system integration: Challenges and opportunities* [Presentation]. Plenary speaker at National Defense Industrial Association Human Systems Conference, Alexandria, VA. https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2015/human/WedENDSLEY.pdf

[16] Salazar, G., See, J. E., Handley, H. A., & Craft, R. (2020). Understanding human readiness levels. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 64, No. 1, pp. 1765-1769). https://www.osti.gov/servlets/purl/1807329

[17] See, J. E. (2020b, November 16). *Applying the HRL Scale to Human-Machine Teaming* (No. SAND2020-11664C) [Presentation]. Human-Machine Collaboration for National Security Workshop. https://www.osti.gov/servlets/purl/1830905

[18] See, J. E., Craft, R., & Morris, J. D. (2019). *Human Readiness Levels in the systems engineering process at Sandia National Laboratories* (SAND2019-3123). Sandia National Laboratories. https://www.osti.gov/servlets/purl/1761924

[19] Handley, H. A., & Savage-Knepshield, P. (2020, December). Evaluating the utility of Human Readiness Levels (HRLs) with Human System Integration Assessments (HSIAs). *Proceedings of the Human Factors*

and Ergonomics Society Annual Meeting (Vol. 64, No. 1, pp. 1537-1540). https://journals.sagepub.com/doi/10.1177/1071181320641368

[20] U.S. Nuclear Regulatory Commission. (2012). *Human Factors Engineering Program Review Model* (NUREG-0711 Rev. 3). https://www.nrc.gov/docs/ML1232/ML12324A013.pdf

[21] United Kingdom Ministry of Defence. (2022). Human Factors Integration in defence systems (JSP 912). https://www.gov.uk/government/publications/human-factors-integration-in-defence-systems-jsp-912

[22] SAE International. (2019, February 8). *Standard Practice for Human Systems Integration* (SAE 6906). https://www.sae.org/standards/content/sae6906/

[23] International Organization for Standardization. (2019). *Ergonomics of human-system interaction - Part 220: Processes for enabling, executing and assessing human-centred design within organizations* (ISO 9241-220:2019-3).

[24] Hale, K., Fuchs, S., Carpenter, A., & Stanney, K. (2011, September). A scale for assessing human factors readiness levels. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 55, No. 1, pp. 2030-2034). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.994.5937&rep=rep1&type=pdf

[25] Johnston, M., Giudice, K. D., Hale, K. S., & Winslow, B. (2013, July). Development of a system for communicating human factors readiness. *International Conference on Human Interface and the Management of Information* (pp. 475-484). Springer, Berlin, Heidelberg. https://link.springer.com/content/pdf/10.1007/978-3-642-39226-9_52.pdf

[26] Garcia, A., Ganey, N., & Wilbert, J. (2017, September). Human readiness assessment: A multivariate approach. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 61, No. 1, pp. 106-109). https://journals.sagepub.com/doi/10.1177/1541931213601495

[27] See, J. E. (2020a, November 10, 12-13). *Maturation of the Human Readiness Level Scale* [Presentation]. National Defense Industrial Association 2020 Virtual Systems and Mission Engineering Conference. https://www.osti.gov/servlets/purl/1825626

[28] Federal Aviation Adminstration. (n.d.a.). AMS policy vs guidance. https://fast.faa.gov/Policy_VS_Guidance.cfm

[29] Federal Aviation Administration. (n.d.b). Policy for critical lifecycle management functions and disciplines. https://fast.faa.gov/docs/acquisitionManagementPolicy/AcquisitionManagementPolicy_4.pdf#nameddest=policy4

[30] Federal Aviation Administration. (n.d.c.). FAA acquisition system toolset. https://fast.faa.gov/